THREE CRUISES OF THE BLAKE, VOL. I.

BULLETIN

OF THE

MUSEUM OF COMPARATIVE ZOÖLOGY

AT

HARVARD COLLEGE, IN CAMBRIDGE.

VOL. XIV.

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Superintendents U. S. Coast and Geodetic Survey.]

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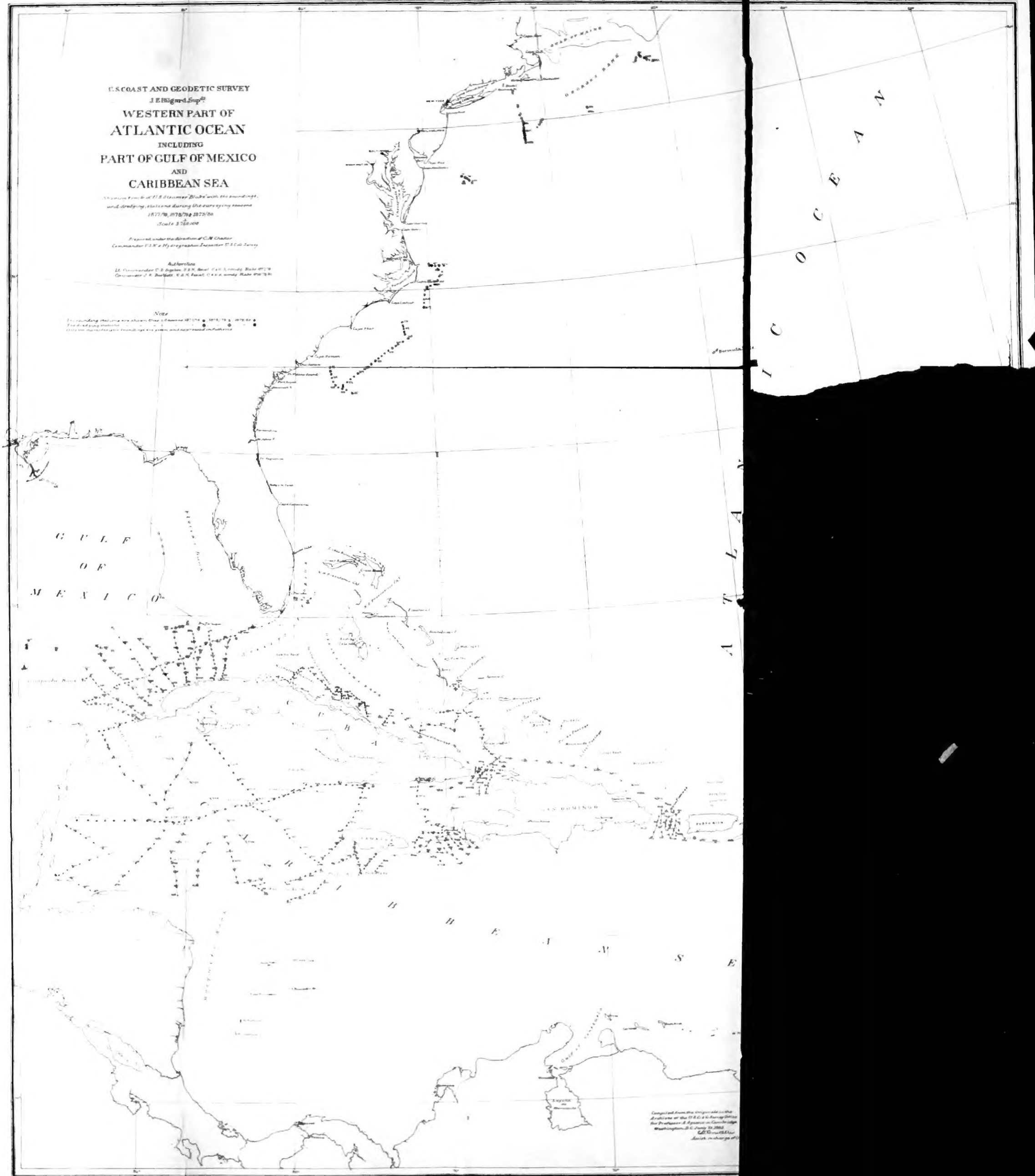
U.S. COAST AND GEODETIC SURVEY
WESTERN PART OF
ATLANTIC OCEAN
INCLUDING
PART OF GULF OF MEXICO
AND
CARIBBEAN SEA
Note
G U L F
O F
M E X I C O
A T L A N T I C   O C E A N
C U B A
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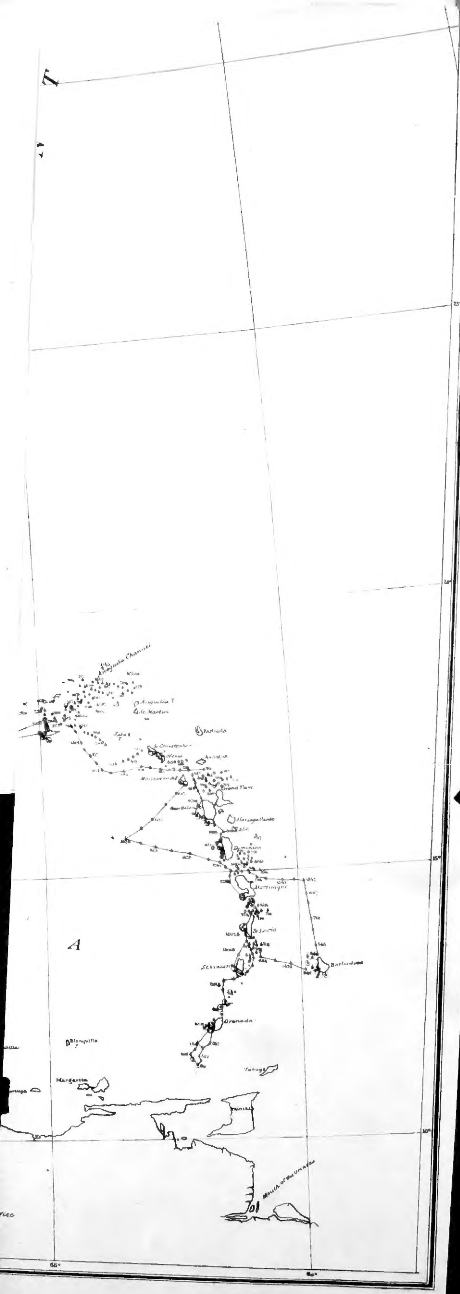
SAN DOMINGO



Anguilla Channel
Anguilla I
St Martin
Barbuda
Antigua
Montserrat
Grand Terre
Dominica
Martinique
St Lucia
Barbadoes
Grenada
Tobago
A
Blanquilla
Margarita
Mouth of the Orinoco
65°
60°
15°
10°

A Contribution to American Thalassography.

THREE CRUISES

OF THE

UNITED STATES COAST AND GEODETIC SURVEY

STEAMER "BLAKE"

IN THE GULF OF MEXICO, IN THE CARIBBEAN SEA, AND ALONG THE ATLANTIC COAST OF THE UNITED STATES, FROM 1877 TO 1880.

BY

ALEXANDER AGASSIZ.

IN TWO VOLUMES.

VOL. I.

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DEDICATED

TO

The Memory of

L. F. POURTALÈS,

A PIONEER IN DEEP-SEA DREDGING,

BY

ALEXANDER AGASSIZ.

CONTENTS OF VOLUME I.

Note. — A List of the Figures will be found at the end of Volume II.

INTRODUCTION.

My connection with the thalassographic work of the Coast Survey dates back to 1849, when, as a boy, I accompanied Professor Agassiz in his cruise on the "Bibb" off Nantucket, and afterward, in 1851, served as aid on his survey of the Florida Reef. More than twenty years later I returned to this line of study, in a report on a part of the collections made by Pourtalès in the "Bibb" in deep water in 1867–68, and since that time I have been engaged, with little interruption, more or less directly in deep-sea work. It was therefore natural that I should accept the invitation given me in 1877, by Mr. Patterson, the Superintendent of the Coast Survey, to continue, under its auspices, the work in which I had begun my biological studies. If at times the physical difficulties encountered were somewhat discouraging, it was a great pleasure to find that my professional training as an engineer not only contributed in no small measure to the success of the expedition, but also increased my interest in the many problems of deep-sea explorations.

The field of work opened to naturalists by thalassographic surveys is of the greatest importance. The materials collected throw a flood of light on our knowledge of the conditions of animal life in deep water, and promise the most important general conclusions on terrestrial physics and on geology. Fascinating as has always been the study of marine life, this interest has greatly increased since we have found the means of reaching the abyssal fauna. Light has suddenly been shed on many vexed problems concerning the geographical distribution of animals and plants and their succession in time from former geological periods to the present day. New notions of geologi-

cal horizons and periods loom up before us, and the problems concerning the formation of continents and oceanic basins now present themselves from a very different standpoint. Our ideas regarding the formation of many marine deposits have been greatly modified, and we are now able to look back into the past history of the world with more confidence than heretofore.

The plans of the equipment of our expeditions were naturally discussed with the Superintendent of the Coast Survey, with the commanding officers, Lieut.-Commander Sigsbee and Commander Bartlett, and during the cruise the criticisms and suggestions of the commanders, of Lieutenants Ackley, Sharrer, Mentz, and of the other officers of the ship, Messrs. Jacoby, Reynolds, and Peters, constantly modified our methods of work, and gradually changed our apparatus to such an extent that it would have been difficult to recognize the original dredging implements as first devised. The exact share of each in these changes it is impossible to state.[1]

During the season of 1877–78 the dredging operations carried on from December to March by the "Blake," in command of Lieut.-Commander C. D. Sigsbee, U. S. N., extended from Key West to Havana, from Havana westward along the north coast of Cuba, from Key West to the Tortugas, thence to the northern extremity of the Yucatan Bank, to Alacran Reef, back to Cape Catoche, and across to Cape San Antonio, returning to Key West, and from Key West to the Tortugas, and northward to the mouth of the Mississippi River. See track of "Blake," Fig. A. After I left the "Blake" that year, Sigsbee occupied a number of stations off Havana in search of Pentacrinus, of which we had obtained a quantity of fragments in the early part of the cruise. He succeeded in discovering their haunts, and was the first to dredge a number of specimens from a locality not far from the Morro Light, which has become known as Sigbee's Pentacrinus ground.

Notwithstanding the delays incidental to bad weather and to the unfortunate grounding of the "Blake" at Bahia Honda while in charge of a Spanish pilot, so that nearly three weeks

[1] A detailed description of the "Blake" equipment is given by Sigsbee in his memoir on deep-sea sounding and dredging, published by the U. S. Coast Survey.

were lost before the ship could be floated and again in condition to resume work, the following lines were run during the season of 1877–78 : —

1. One line from Havana to Sand Key, in depths of from 320 fathoms to 951 fathoms.

2. A second line along the coast of Cuba, from Havana to a short distance west of Bahia Honda, from 292 fathoms to 850 fathoms.

3. A short line of about 40 miles northerly from the Tortugas, from 111 fathoms to 37 fathoms, to examine the character of the fauna of the Florida Bank to the westward of the mainland as far as the hundred-fathom curve.

4. A line from the hundred-fathom curve on the west side of the Florida Bank about 30 miles north of the Tortugas, across to the hundred-fathom curve on the northeastern side of the Yucatan Bank, from 110 fathoms to 1,920 fathoms, and back to 95 fathoms.

5. A line from 1,568 fathoms north of the Alacran Reef, from the deep basin extending from the northern slope of the Yucatan Bank toward Vera Cruz up to 84 fathoms on the northern edge of the Yucatan Bank.

6. A line from the hundred-fathom curve on the north side of the Yucatan Bank to Alacran Reef, and from there in a southeast direction into 20 fathoms off the Joblos Islands, diagonally across the Yucatan Bank.

7. A line in the trough of the Gulf Stream from north of Cape San Antonio to Sand Key, Florida, from 1,323 fathoms to 339 fathoms.

In all, about 1,100 miles of lines, taking the shortest distances from point to point.

In this first season the number of casts made with dredge and trawl were over fifty, from 300 fathoms to 1,920 fathoms; of these forty-three were successful hauls. In making them we lost only 200 fathoms of steel rope.

8. Our operations were confined to dredging along a line to the northward of the Tortugas, running, in a general way, parallel to the hundred-fathom curve of the western edge of the Florida Bank. This line was extended northward to about the latitude of Tampa Bay, a distance of some 200 miles.

9. A line was run from that point directly for the mouth of the Mississippi, a distance somewhat less than 200 miles.

The weather during the greater part of our trip from the Tortugas to New Orleans was very bad, as is usually the case during March in the Gulf of Mexico. We could do but little beyond ascertaining, in the most general way, the faunal characteristics of the lines run between Key West and New Orleans. At New Orleans Mr. Garman and I left the "Blake," an event which must have been a relief to the officers, more particularly to the executive officer, Lieutenant Ackley, who was once more free to put the ship in an orderly condition. The work of dredging is not conducive to cleanliness, and during the whole time I was on board no routine was ever allowed to interfere with our work, Lieutenant Ackley himself always being the first to see that everything was in readiness for our dredging operations at all times. That the interest shown in the work by the other officers of the "Blake," Messrs. Sharrer, Jacoby, Moore, Sigsbee, and Dr. Nourse, did not flag after my departure is amply demonstrated by the collections made off Havana, containing as they do some of the most valuable specimens of the expedition, all in an excellent state of preservation. The "Blake" subsequently returned to Key West to continue her regular work of sounding between the Tortugas, the coast of Cuba, and the Yucatan Bank. On the way to Key West, a few casts were made by Lieut.-Commander Sigsbee on the Florida Bank, in Lat. 26° 31′, Lon. 89° 3′, in a depth of 119 fathoms, at a point where a good notion of the fauna of the Florida Bank could be obtained.

As connected with the work of oceanic exploration carried on under the auspices of the U. S. Coast Survey, I may also mention a visit to the Tortugas during 1881. I left Key West for the Tortugas in the middle of March on the "Laurel," which Lieut.-Commander Wright, in accordance with the permission of the Lighthouse Board, had kindly ordered to transport me and my assistant, Dr. Fewkes, to the Tortugas, with the necessary coal for the steam launch which had been placed at my disposal by Mr. Patterson. The launch I found ready at Key West, fully equipped, manned, and provisioned, thanks to the care of Lieut.-Commander Winn.

While at the Tortugas we were allowed by the Secretary of War to occupy such quarters at Fort Jefferson as were not otherwise needed, and we selected as a laboratory a large room, with excellent light, on the ground floor of the barracks. On days when the weather was not suitable for surface work outside in the Gulf Stream, I employed the launch in cruising inside the reef, and thus examined carefully the topography of the different groups of corals characteristic of the Florida reefs. The results of this visit, as well as those made on previous occasions, have enabled me to give a somewhat extended account of the Florida reefs in a special chapter of this book. We remained at the Tortugas five weeks, and returned to Key West in the revenue steamer "Dix," Captain Scammon, whom the Secretary of the Treasury had authorized to assist us as far as practicable. At Key West we occupied as a work-room the loft of the Navy Depot building, and continued our studies of the pelagic fauna of the Gulf Stream.

During the second dredging season (1878–79), the "Blake" was in charge of Commander J. R. Bartlett, U. S. N. The cruise extended from Washington to Key West, from Key West to Havana, from Havana to Jamaica through the Old Bahama Channel and Windward Passage, from Jamaica to St. Thomas along the south coast of Hayti and Porto Rico. From St. Thomas the "Blake" visited Santa Cruz, Saba Bank, Montserrat, St. Kitts, Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines, and Grenada; she also carried the dredgings south as far as the hundred-fathom line off Trinidad, returned to St. Vincent, and finished the dredging operations at Barbados.

On November 27, 1878, I joined the "Blake" at Washington for a second dredging cruise. We intended to proceed to Nassau, and there devote a few days to dredging and sounding, in order to trace the connection between the fauna of the northern extremity of the Bahama Banks and that of the Straits of Florida. On account of rough weather this was not deemed prudent, and we were compelled to put into St. Helena Sound; and, for the same reason, when off Jupiter Inlet, instead of crossing the Gulf Stream to make Nassau, it was thought best

to put into Key West. From there, when the weather moderated, we started for Kingston, Jamaica, calling at Havana for the purpose of making a couple of hauls on the Pentacrinus ground discovered by Sigsbee off the Morro Light. (Fig. B.)

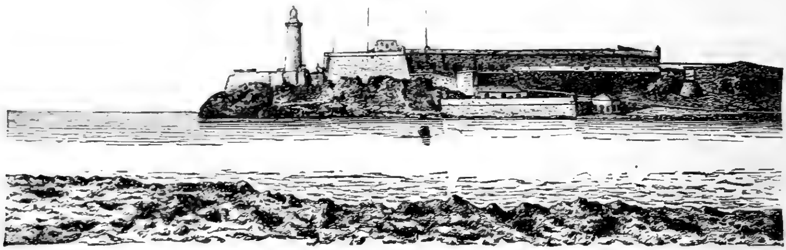


Fig. B. — Morro Castle (Havana), with modern limestone terrace in foreground.

We made two casts of the dredge, passing from 175 to 400 fathoms, and obtained a few specimens of Pentacrinus. We kept on along the northern shore of Cuba, through the Old Bahama Channel, without stopping to sound or dredge, Pourtalès having in former years dredged and sounded from the "Bibb," Acting Master Platt, U. S. N., over the greater part of this line.

In the dredgings taken off the southeastern end of Jamaica we did not bring up anything of great importance. From Jamaica we were obliged, owing to the strong trades, to keep on toward St. Thomas, without either sounding or trawling till off Porto Rico. During the winter months the trades blow sufficiently hard to make dredging and sounding quite uncomfortable on a vessel of the size of the "Blake." We therefore had no opportunity of adding anything to the hydrography of that part of the Caribbean Sea.

The region over which we chiefly worked this year reached from St. Thomas to Trinidad. Over a limited area like this, it was possible to cover the ground very satisfactorily. The work done off the principal islands began usually at the hundred-fathom line, and extended into the deepest water off the lee side of the Caribbean Islands. But little could be done in the way of dredging in the passages between the islands or to the windward of them, owing to the strong trades. While working off

Barbados we undoubtedly obtained a fair representation of the fauna to the windward of the Caribbean Islands, which does not seem to differ from that of the lee side.

Tempting as it would have been to devote more time to a prolonged study of the islands within sight of which we worked for a whole winter, it was only natural that our interest in the land should give way to our work at sea.

Our acquaintance with the Caribbean Islands was limited to such examination as we could make from the deck of the "Blake," as we steamed from our night's anchorage out into deep water, or steamed and trawled slowly for days within sight of the same island. Under these circumstances, we could not fail to obtain a familiarity with their topography which few of the inhabitants, or of even the more enthusiastic and energetic foreign travellers, could have. The few excursions we were able to make in the interior, while coaling or cleaning boilers preparatory to getting under way again, gave us charming glimpses into regions rarely visited as yet. The traveller in these islands is dependent almost entirely upon private hospitality, which, however delightful it may be, is a great bar to independent action and exploration. But the time is not distant when the increased facilities of communication will call into existence the hotels which alone are needed to make the West India Islands the winter resort of innumerable tourists, who now go to Florida or to the south of Europe. They will find in this new resort the most lovely scenery imaginable, the perfection of winter climate, and unbounded hospitality; and the lover of nature will have endless occupation in the ever-varied rambles which each island affords.

As seen from the sea, the contrasts offered by the different islands is most striking. I will not here speak of Cuba, Jamaica, Hayti, or Porto Rico, small continents as it were, although with each of these the "Blake" has some special association. During the first dredging cruise, the northern shore of Cuba from Havana westward was partly explored by the "Blake," and while Bahia Honda will always remain to the commander a most unpleasant landmark in the history of the cruise, because our Spanish pilot ran us ashore as we entered the harbor, it is

marked with a red letter in my journal as the spot where the wonderful young Holopus was dredged.

The difficulty of dredging in the region of the trade winds with a small vessel like the "Blake" is very great. No extended explorations to windward were possible, but fortunately we were able to reach deep water under the lee of the Lesser Antilles. In the channels between the islands the sea was usually too rough to allow us to sound even, and when steaming to windward, as during the passage from Jamaica to St. Thomas, all deep-sea work was out of the question, as we could scarcely forge ahead, and we rejoiced to reach at last the shelter of St. Thomas.

The appearance of the islands as seen from the deck of the vessel is most interesting, each one having a physiognomy of its own, yet all modifications of one type. If the physical features are well marked, the national characteristics of the different groups are no less so. Where Englishmen, Frenchmen, and Spaniards once fought for the supremacy of the sea and the possession of the New World, they are now content to live in friendly rivalry with the Danish and Swedish West Indian colonies.

The island of St. Thomas, with its land-locked harbor, near the junction of the Lesser and Greater Antilles, is the central West Indian station. It is a long, low, undulating island, with summits reaching perhaps 800 feet in height, continuations of the crests of the extensive submarine bank which forms the Virgin Islands, one of which, Virgin Gorda, rises to nearly 1,800 feet. These islands are almost bare, and the larger ones, covered with wrecks of plantations and remaining uncultivated, are gradually being abandoned. The opposite island, Santa Cruz, is, like the Virgin Islands, low, but its slopes are covered from base to summit with brilliant fields of sugar-cane, and dotted here and there with factories and thriving towns.

In the channel separating St. Thomas from Santa Cruz we find the deepest water in which the "Blake" dredged, and near Frederichstæd, at the western extremity of the island, we come upon one of those rich localities characterized by an extraordinary abundance of deep-sea animals in comparatively shallow water.

From Santa Cruz we steam across the Saba Bank, dredging occasionally as the sea permits, and pass under the lee of Saba, an old volcanic cone, which rises 1,500 feet sheer out of the water. Steps lead up from the water's edge, for a height of 800 feet, to the bottom of an ancient crater, where a large settlement exists. At Saba the greater part of the former rim of the crater has disappeared, while at St. Eustatius the cone is broken only at one point.

We next come to St. Kitts, perhaps one of the most striking of the West India Islands, in its exhibition of their typical structure, — a single peak, rising to about 3,700 feet, but with gentle slopes (Fig. C.), formed by old lava streams washed down by

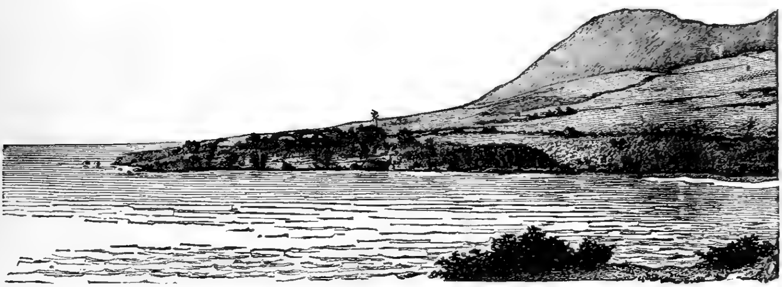


Fig. C. — Western Slope of St. Kitts.

torrential tropical floods during the rainy season, and deeply furrowed by diminutive cañons. The whole outline of the island is composed of graceful slopes, which become less steep as they approach the sea, and covered nearly to the highest point with flourishing sugar plantations, the steeper grades towards the top of the crater becoming more and more barren as they near the summit.

Such are in general the features of nearly all the Windward Islands; the scenery varies as we pass from islands with one summit to others with two or more peaks, and with slopes more or less chiselled by the rains. Such islands as Saba, Montserrat, St. Kitts, or St. Vincent, with a single central peak, present a marked contrast to larger islands, like Guadeloupe, Martinique, and Dominica, or to islands like the Grenadines, forming disconnected ridges rising from deep water, and differ still more

from geologically recent islands like Sombrero, Barbuda, Antigua, and Barbados. St. Kitts may be said to form a twin island with the adjoining Nevis, which has a soufrière of its own rising to 2,000 feet.

Montserrat comes next, another small volcanic island, well known now for the large amount of lime-juice it exports. We then pass by the lonely island of Redonda, with its cloud-capped summit. Nearly all the higher peaks of the Windward Islands are usually hidden from view by a cap of clouds, massed against the windward sides, where the trade winds, saturated with moisture, strike the cold flanks of the summit.

The huge central mass of Guadeloupe, perhaps the most imposing of the West Indian volcanoes, rises to a height of at least 5,000 feet. The larger island is separated by a swamp from the Grande Terre, a low bank of recent limestone at the base of the central volcano of Guadeloupe. The steep slopes near the summit are covered with forests, but pass gradually into the long, gentle cultivated slopes, which in their turn fade imperceptibly into the arid tracts of Grande Terre itself.

On the south, Guadeloupe is flanked by outlying islands, the Saintes and Marie-Galante, where we dredge in vain for some of the treasures of the deep, supposed to have been fished up in the intervening channels by French naturalists at the beginning of this century.

As we approach Martinique, it seems to consist of three separate mountain masses, not smoothly rounded, as in the more northern islands, but with deeply furrowed flanks, cut out by rains and torrents, and innumerable winding valleys, cultivated from the water's edge almost to the highest summits. The island is crossed in all directions by excellent roads, and dotted over with villages and plantations. The slopes of the deeper valleys and the more inaccessible bottom lands are covered with forests and with groves of tree ferns. Near the plantations, avenues of royal palms rear their heads high above the dark mango, orange, and lime trees. On the lee side of the island is St. Pierre, the commercial centre of the French West Indies, where at every step one is reminded of a French provincial town. To the south is the naval station of Port de France,

separated by an inlet from the hamlet where the Empress Josephine was born.

Nowhere else among the West India Islands are the slopes so deeply furrowed as on the flanks of Dominica, a long comparatively low ridge, without prominent peaks, but with many signs of active volcanic action. The island is as yet but little cultivated, and on all sides one meets indications of its former French dependency. But here, as in many of the islands which have passed into English hands, and have been left to shift for themselves, the results have not been satisfactory. While at anchor in Petite Baie d'Arlet, we could not but be pained at the wholesale destruction of humming-birds going on. Ten thousand skins are annually exported from that single settlement.

In St. Lucia, the most fertile of the West India Islands, there is a handful of English settled at Castries, a deserted town,

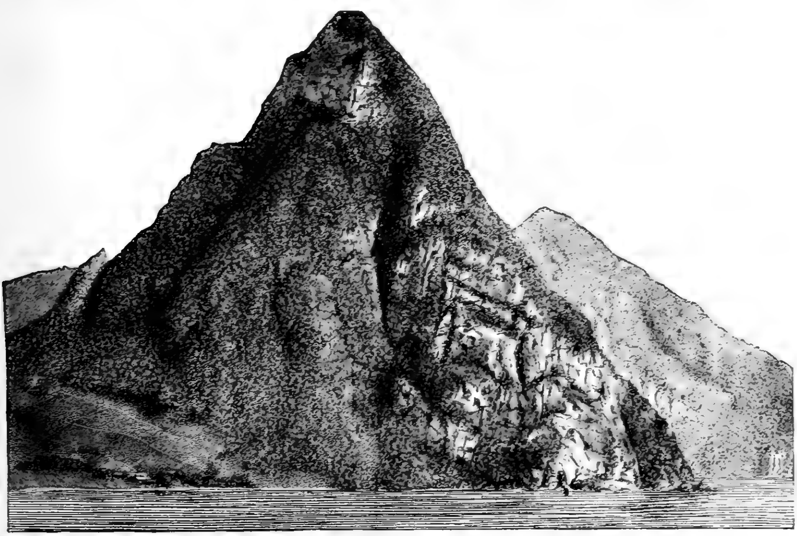


Fig. D. — Pitons, St. Lucia.

neglected, like the island itself, and nearly abandoned. The island is thickly wooded in parts; at the south end on the lee side are two remarkable peaks, the Pitons, rising 2,700 feet perpendicularly out of the sea. (Fig. D.) Between them

extends a lovely bay, where we anchored one evening, almost touching the little beach, close to which stands a small collection of negro huts.

Coming to St. Vincent, we find it fairly cultivated on the southern side. (Fig. E.) Its greater prosperity is undoubtedly

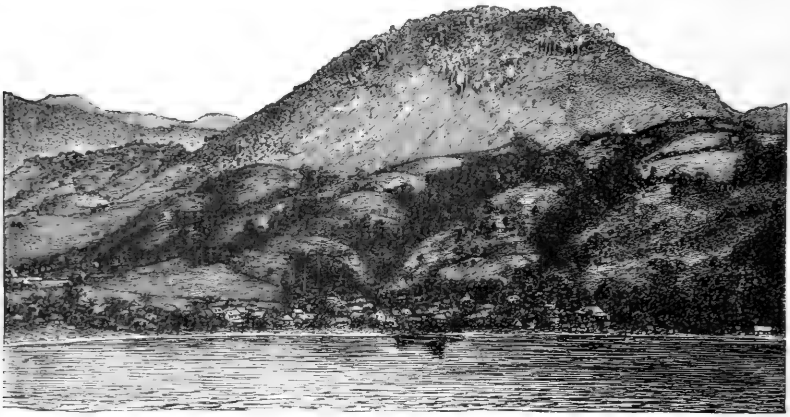


Fig. E. — Kingstown, St. Vincent.

due to its more varied agricultural interests, and the fall in the price of sugar has not proved so disastrous there as in those islands where the sugar crop forms the sole support of the population. From the southern extremity of the highest peak, the soufrière in 1812 sent out vast sheets of lava during an eruption which lasted for three days. It was heard eighty miles off, at Barbados, which was enveloped in darkness and covered with volcanic dust, while a heavy tidal wave swept its shores.

From St. Vincent we pass by the Grenadines, small, low, uninteresting islands, with names more romantic than their scenery; they are formed by the summits of a volcanic ridge rising abruptly out of deep water.

We come finally to Grenada, the last of the Lesser Antilles. Its excellent though small harbor reminds one of Malta on a small scale, and the resemblance is not lessened as one goes climbing the steep streets from the docks to the more level region where Government House is located. At the entrance of the harbor is Fort Richmond, and behind it rises the rim of

an extinct crater, leading up to Mount Maitland, the highest summit of Grenada.

There yet remain Tobago and Trinidad, but they are bits of the South American continent, left stranded on the continental shelf.

Isolated from all the other islands, perhaps the least attractive of them, stands Barbados, a volcanic cone, entirely surrounded by coral terraces, which completely hide the cone. (See Figs. 39, 46.) In this the most flourishing of the English islands the negro population is very dense. Barbados is comparatively as thickly populated as Belgium, and every inch of the soil is cultivated. It is a huge sugar plantation, dotted over with windmills and sugar-houses. Bridgetown has somewhat the appearance of an Italian town. Its streets are crowded with negroes, who, like their West Indian brethren, are noted neither for morality nor cleanliness. Only about one tenth of the population is white. There is a large garrison, so that Bridgetown has its parade, cricket-ground, clubs, and all that renders a British colony dear to an Englishman in exile.

The northeastern islands, Antigua, Barbuda, and Sombrero, we did not visit. They are geologically more recent, and are placed upon the eastern edge of the shallow plateau forming the northern extremity of the submarine bank upon which the Windward Islands rise. Of course they held out no inducement to the "Blake" expedition, which was in search of the deep water on the lee side of this plateau.

For the third cruise I joined the "Blake," commanded by Bartlett, at Newport, late in June, 1880. According to instructions, we proceeded to the northeastern edge of George's Shoal, where we ran our first line of dredgings from the hundred-fathom line to a depth of nearly 1,250 fathoms. Our second line was run to the southeast, off Montauk Point. This was interrupted by bad weather. We were compelled to put into Newport, and completed the line on our return from the South. This line extended to about 1,400 fathoms.

On leaving Newport for the second time, we steamed directly for Charleston, S. C. A line of dredgings was run from the hundred-fathom line normal to the coast, directly across the

Gulf Stream, to a distance of about 120 miles to the eastward of Charleston. Finding that our depth did not increase at that distance, — our greatest depth not being much more than 350 fathoms, — Commander Bartlett thought it prudent to return towards shore, to the so-called axis of the Gulf Stream, and to run a line in a northeastern direction parallel to the coast in the trough of the Gulf Stream. To our great astonishment the depth still did not increase, and we carried from 250 to less than 300 fathoms until we reached nearly the latitude of Cape Hatteras, when in a short distance there was a very rapid drop from 352 fathoms to 1,386 fathoms. A fifth line was run normal to this northern slope of the Gulf Stream plateau, to a depth of 1,632 fathoms. A sixth line was run to the northward of Cape Hatteras, to a depth of 1,047 fathoms. A seventh line was run east, off Cape May, from the hundred-fathom line to 1,200 fathoms.

In accordance with an arrangement made with the late Sir Wyville Thomson, by which the collections made by American and English deep-sea expeditions were to be sent to the same specialists, the collections of the "Blake" were worked up under the most favorable conditions. But as the greater part of the collections made during the third cruise of the "Blake" cover the extension into deep water of the ground already in part occupied by the United States Fish Commission, the collections made north of Cape Hatteras were sent to the naturalists to whom the collections of the Fish Commission had been intrusted.

In the preparation of the final Reports published upon the "Blake" collections, the special knowledge of those who have carefully followed the development of a limited group of invertebrates, their palæontological and geographical distribution, their migrations, and the causes which have probably led to the existing condition of things from a former geological period, has been indispensable. I cannot adequately express my thanks to the gentlemen who have so kindly undertaken the laborious task of preparing the Reports of the "Blake" collections. Without their assistance, the work would have been neither prompt nor satisfactory.

The Report on the Hydroids was written by Prof. George J. Allman; on the Crinoids, by Dr. P. H. Carpenter; on the Hydroids of the first expedition, by Prof. S. F. Clarke; on the Crustacea, by Prof. Alphonse Milne-Edwards; on the Annelids, by Prof. Ehlers; on the Myzostomidæ, by Prof. L. von Graff; on the Isopods, by Mr. Harger; on the Ophiurans, by Mr. Lyman; on the Starfishes, by Prof. Perrier; on the Corals, by Pourtalès; on the Sponges, by Prof. Oscar Schmidt; on the Bryozoa, by Prof. Smitt; on the Holothurians, by Dr. H. Théel; on the Anthozoa, by Prof. Verrill; and on the Pygnogonidæ, by Prof. E. B. Wilson. Mr. Garman, who accompanied me as assistant during the first cruises of the "Blake," was indefatigable in caring for the collections brought together, and he also wrote the Report on the Selachians.

In addition to the preparation of the special Reports in their departments, I am also indebted to Prof. Goode and Dr. Bean, for additional notes on the Fishes; to Mr. Dall, for the greater part of the account of the Mollusks; to Mr. Lyman, for that of the Ophiurans; to Mr. Fewkes, for that of the Acalephs; and to Prof. S. I. Smith, for that of the Crustacea. To Mr. John Murray I owe special thanks for his suggestions and assistance in writing the chapter on Submarine Deposits. Commander Sigsbee was kind enough to look over the chapter relating to the equipment of the "Blake." Commander Bartlett of the Hydrographic Office has read the chapters on the Gulf Stream and on the hydrography of the Caribbean region; he has also supervised for this volume the drawing of several of the accompanying maps.

I have myself prepared the Reports on the Coral Reefs, the Surface Fauna of the Gulf Stream, the Sea-Urchins, and a few minor papers relating to the cruises of the "Blake."

To the U. S. Coast Survey Office I am of course under the greatest obligation for copies of the many reports, maps, and sections contained in that office to illustrate the hydrography of the West Indian region and of the Gulf of Mexico, and that of the Atlantic coast of the United States. Prof. James D. Dana has kindly read some of the chapters relating to the geological problems discussed, and to Mr. Winsor I am indebted

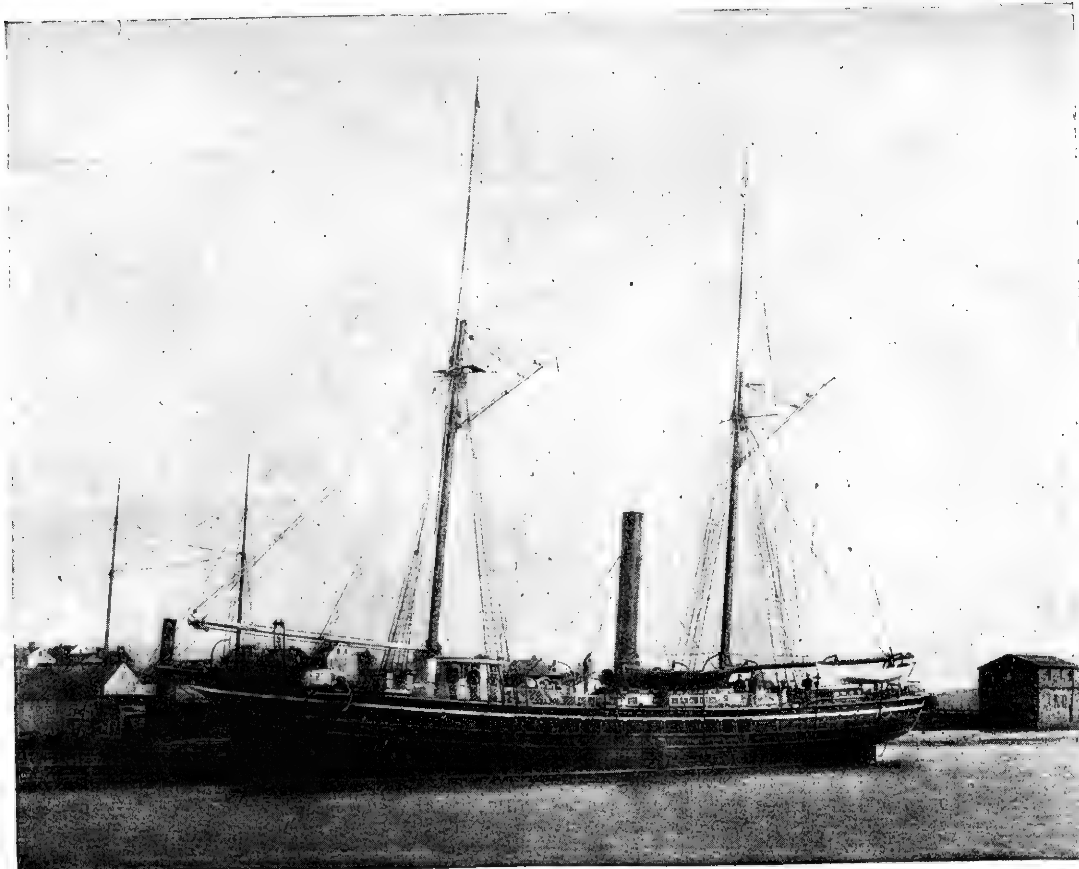
for many suggestions relating to the history of the discovery of the Gulf Stream.

The commanders of the "Blake," Lieut.-Commander Sigsbee and Commander Bartlett, were ever ready to promote the special interests of the cruise during my connection with the vessel, and they were most cordially supported by the officers and crew in this novel work, so foreign to their usual routine.

In arranging the following sketch of the work of the "Blake" expeditions, I have collected in different chapters what I had to say regarding the special subjects of which they treat, based upon the experience gained during the voyages with which I have been associated. The greater part of these chapters has been in type for more than two years; this will account for some anachronisms, and for some omissions of reference to publications which would otherwise have been noticed. While of course dealing with the subject of Thalassography as a whole, I have avoided as far as possible all unimportant comparative work.

ALEXANDER AGASSIZ.

Museum of Comparative Zoölogy,
Cambridge, *December*, 1887.



THE "BLAKE."

THREE CRUISES OF THE "BLAKE."

I.

EQUIPMENT OF THE "BLAKE."

The principal object of the hydrographer is to ascertain the depth of the sea at any given point, and this seems at first glance a very simple process. Sounding in a few fathoms with an ordinary lead-line and a heavy sinker presents no difficulties, and even in one hundred fathoms the hand lead-line can be used with a moderate degree of accuracy. Beyond this, the problem is very different. I well remember my own first experience of sounding, in Lake Titicaca, in not more than one hundred and fifty-four fathoms, — when more than five hundred fathoms of line were payed out and "no bottom" reported. This unsatisfactory result was due simply to the insufficiency of weight of the sinker. The experience of those who with the ordinary apparatus have attempted to sound at still greater depths in the oceanic basins has been the same. As the sinker descends, the weight of the rope to which it is attached becomes, of course, greater and greater; the friction also increases to an alarming extent; and the action of the currents, where there are any, on the immense surface presented to them by say one thousand or fifteen hundred fathoms of two-inch rope, is sufficient not only to counteract the very moderate weights used as sinkers, but to exert a lateral force so strong in many cases that the depth seems to increase in proportion to the amount of line payed out, as if it were indeed fathomless.

It is not astonishing, therefore, to find recorded such extraordinary depths in some parts of the Atlantic as eight thousand

fathoms and "no bottom," or to find, as was found by the "Blake" in the Old Bahama Channel, where the current was running at the rate of four knots an hour, a depth of only four hundred and fifty fathoms when sounding with wire, on the very spot where previous rope soundings indicated eight hundred fathoms and "no bottom."

This problem of deep-sea sounding was attacked from many sides by American, English, and French naval officers, and the most successful results were obtained by increasing the weight of the sinker in proportion to the size of the line. The line was thus gradually diminished in size in order to reduce both its weight and the friction, and comparatively accurate soundings were made with a stout cod-line and a heavy sinker (one hundred pounds). This method of sounding had, however, its own objections, for it involved the loss of the line, which was not strong enough to bring back the sinker, and thus also no specimen of the bottom could be obtained.

Unsuccessful attempts to sound with wire as a substitute for rope were made as far back as 1849, both by English and American naval officers. Their failures led to ever-renewed efforts to improve the methods of sounding with line, and all the recent more accurate deep-sea soundings taken with rope or line have been made with comparatively small lines weighted with heavy sinkers, which caused the line to run out with great velocity. This velocity, of course, decreased as the depth increased, and the time of reaching the bottom was indicated theoretically by an abrupt change, — one practically, however, very difficult to observe with great accuracy. Consequently, a good deal of line would run out before the certainty of having reached bottom became apparent.

It is to the need of submarine cables that Thalassography[1] owes its great development. While a knowledge of the depth of the sea is one of the first requisites for the laying of cables, the character of the bottom is also an important element, and an instrument which would bring up a good sample of the bottom became therefore an absolute necessity. Professor John

[1] The need of some single word to express the science which treats of oceanic basins has led to the construction of this term.

M. Brooke, then passed midshipman, devised a very ingenious apparatus (Fig. 1), so contrived as to disconnect, on touching bottom, the heavy sinker — an old cannon-ball with a hole bored through it — required for running out the sounding-line to great depths. This made it possible to use a very heavy sinker compared to the size of the line, because the latter, being instantly freed from the weight on reaching the bottom, need only be strong enough to bring back the light iron rod with the collecting cup attached to it which passed through the sinker. While going down, the cannon-ball was suspended by slings from movable cranks; on reaching bottom the end of the line became slack, the weight pulled down the arms, and the slings slipped off, leaving the shot behind, and the line free to bring back the small sample of the bottom attached to the armature of the rod. This armature has since been greatly modified and the rod changed to a cylinder by Commander Belknap, so that in the deep-sea sounding-machine as used on the "Blake" quite a large sample of the bottom can now be brought up. The apparatus used by Brooke for detaching has also been greatly improved by Lieutenant-Commander Sigsbee; his detacher is now attached to the Belknap cylinder when deep soundings are made. The principle upon which it works is that of a bell-crank suspended excentrically; so long as the weight of the shot is suspended from the crank, it cannot be detached, but the moment the extremity of the sounding-cylinder touches bottom, the pressure is relieved and the bell-crank is tripped, the shot slips off, and the sounding-cylinder and detacher alone, weighing together about fourteen pounds, are drawn up to the surface, with a small quantity of the bottom which has forced its way into the collecting cylinder.

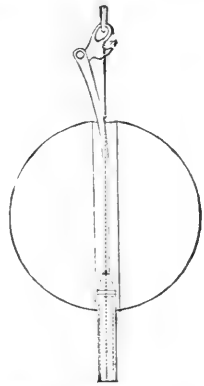


Fig. 1.— Brooke's Detacher. (Sigsbee.)

The examination of the specimens of the bottom collected by the United States Coast Survey was intrusted at first to Professor Bailey, and in later years to Mr. Pourtalès. The results showed at once how large a part in the economy of the life of

the ocean is played by the pelagic forms which, after death, slowly find their way to the bottom and form at the present day deposits in every way similar to those of the chalk. Mr. Murray has, however, from the more extended explorations of the "Challenger," clearly proved that the deposits going on beyond the continental platforms, at great depths in the oceanic basins, find no analogue among the stratified rocks with which we are acquainted. Professor Agassiz and Sir Wyville Thomson also soon became convinced, as a result of their experience in deep-sea explorations, that the oceanic basins were of great antiquity and have always existed, and that the animals found at great depths existed under conditions which have remained unchanged from a remote period of time.

Sir William Thomson, who became interested in deep-sea soundings from his connection with the laying of submarine

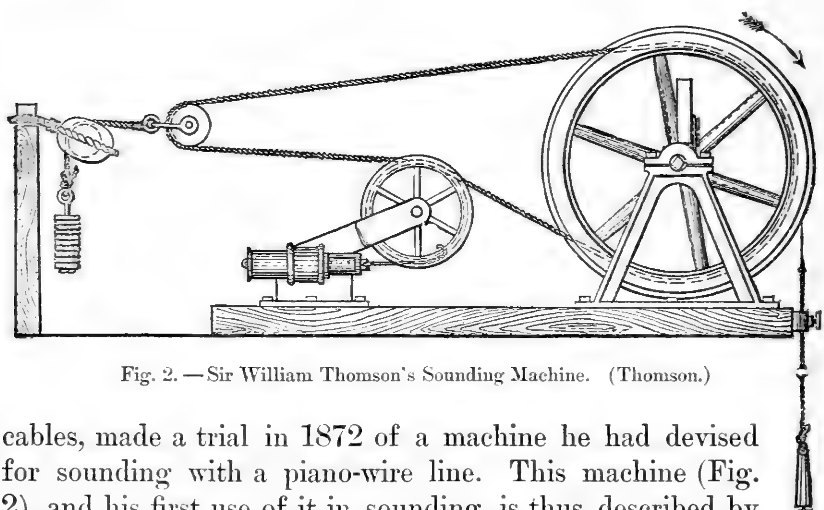


Fig. 2. — Sir William Thomson's Sounding Machine. (Thomson.)

cables, made a trial in 1872 of a machine he had devised for sounding with a piano-wire line. This machine (Fig. 2), and his first use of it in sounding, is thus described by him: "I sounded from the 'Lalla Rookh,' with a lead weight of thirty pounds, hung by nineteen fathoms of cod-line from another lead weight of four pounds, attached to one end of a three-mile coil, made up of ends of piano-wire spliced together and wound on a light wheel about a fathom in circumference, made of tinned-iron plate. The weight was allowed to run directly from the sounding-wheel into the sea, and a resistance exceeding the weight in water of the length of the wire

actually submerged at each instant was applied tangentially to the circumference of the wheel by the friction of a cord wound round a groove in the circumference and kept suitably tightened by a weight."

He says further: "When from two thousand to twenty-five hundred fathoms were running off the wheel, I began to have some misgivings of my estimations of weight and application of resistance to the sounding-wheel. But after a minute or two more, during which I was feeling more and more anxious, the wheel suddenly stopped revolving, as I had expected it to do a good deal sooner. The impression on the men engaged was that something had broken, and nobody on board, except myself, had, I believe, the slightest faith that the bottom had been reached . . . until the brass tube with valve was unscrewed from the sinker and showed an abundant specimen of soft gray ooze. . . . That one trial was quite enough to show that the difficulties which had seemed to make the idea of sounding by wire a mere impracticable piece of theory have been altogether got over."

The first experiment was made in the Bay of Biscay, near a point where the charts showed a depth of twenty-six hundred fathoms. It was entirely successful so far as determining the depth was concerned; and although the machinery for reeling in the wire was defective, the problem had been solved, and the machine only needed very slight modifications to become available for general use. These modifications have since been effected, and many ocean steamers in the English service are now provided with the new machine of Sir William Thomson.[1] All the steamers of the submarine telegraph companies are also

[1] Sir William Thomson has also another sounding-machine, with which it is possible to take soundings in from twenty to one hundred fathoms in a sailing yacht, without once rounding to or reducing speed. He accomplishes this by the use of a long galvanized-iron sinker, provided with tubes lined with chromate of silver. The compression of the air in the tubes, indicated by the line of white lining of the chlorate of silver, measures the height of the column of water to the pressure of which the sinker has been subjected. Soundings of one hundred and twenty fathoms have been made by steamers of the Anchor Line while running at the rate of twelve knots. The "Britannic" has made a sounding of one hundred and thirty fathoms over the Banks of Newfoundland while steaming at the rate of sixteen knots.

provided with them, and for them as well as for the "Blake" sounding with wire to any depth has become a matter of daily routine.[1]

Commander George E. Belknap, U. S. Navy, while commanding the U. S. S. "Tuscarora," during her operations in the Pacific Ocean, in 1873, was the first to test thoroughly the Thomson machine by constant use. While it was evident that the machine for sounding by means of wire gave remarkable results as compared with rope-soundings, its success was apparently due in a great degree to the intelligence, patience, and skill of Commander Belknap and the officers who assisted him. Commander Belknap had always been forced to reel in the wire by hand. Among the plans that presented themselves to Lieutenant-Commander Sigsbee for the improvement of the machine, in order that it might be worked with fewer demands on the watchfulness and ingenuity of those having charge of it, was the interposition of an accumulator on the wire, between the reel and the sinker, which, by showing the strain on the wire at all times during the reeling in, and by easing the sudden jerks on the wire caused by the motion of the ship, would allow of reeling in by steam. A machine for experimental purposes was made in the winter of 1874–5, and the new machine (Fig. 3) was used for three years on board the Coast Survey Steamer "Blake," when that vessel was under the command of Lieutenant-Commander Sigsbee, and engaged in deep-sea work.

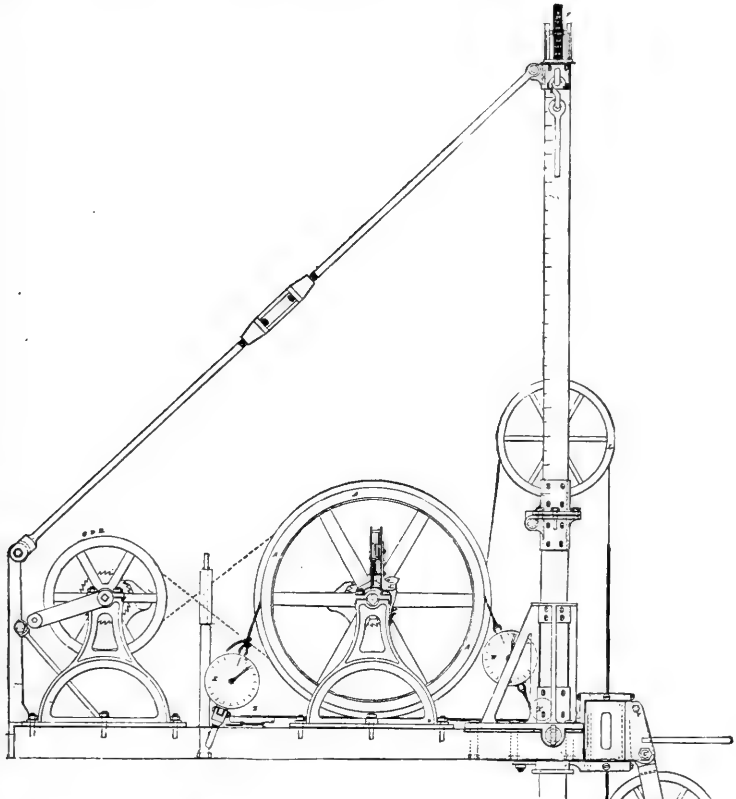
The following account of the main points of the Sigsbee machine is taken from the inventor's detailed description of the apparatus in the Bulletin of the Museum of Comparative Zoölogy, and its improvements in "Deep-Sea Dredging:" —

The reel (*A*, Figs. 4, 5) should be, for convenience, one fathom in circumference of drum, and should have a friction-score which is V-shaped in cross-section. When the sinker strikes the bottom, the momentum of the reel and its remaining wire requires to be quickly overcome by the resistance of the

[1] But even this excellent sounding machine may soon be superseded by Siemens's bathometer, which will enable us to read on deck the depth of the ocean with as great accuracy as we can ascertain the height of mountains by a barometer.

Fig. 3. — SIGSBEE SOUNDING MACHINE. (Sigsbee.)

friction-line, in order that any undue slacking and consequent kinking of the wire may be avoided. To secure this quick stop-



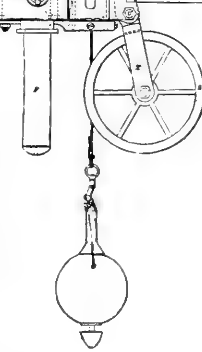


Fig. 4.—Sigsbee Sounding Machine, profile view. (Sigsbee.)

page, the reel should be made as light as the very considerable strength required for reeling in will permit. In reeling in without the reeling-in or strain pulley, it is necessary that the reel should be of sufficient strength to resist the accumulated strain of successive convolutions of the wire under strong tension (the difficulty encountered by Thomson in his first sounding). It is rigidly attached to its axle by a key, and the easy removal of the key would be a convenience, since the reel, without its axle, could be stowed into a

much smaller tank than is necessary when the axle is retained. When a reel containing wire is out of use it is generally kept in a tank of oil. A crank is provided for each end of the axle.

The register (*B*, Fig. 4) is the same as that used by Sir William Thomson, and is worked by a screw-thread attached to the axle of the reel. The register evidently does not record fathoms, an interpolation being necessary in determining, from the reading of the register, the length of wire payed out. It is very handy, however, for keeping an approximate account of the wire payed off, so that the correct amount of resistance can be applied to the reel. The correction of the register is easily found by the method used on board the "Blake." See p. 14.

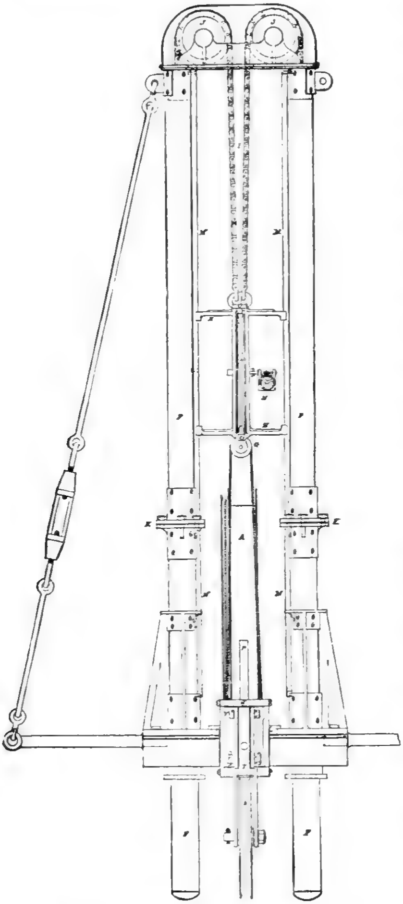


Fig. 5. — Sigsbee Sounding Machine, end view. (Sigsbee.)

The reeling-in or strain pulley (*C*, *D*, *E*, Fig. 4) is composed of three separate pulleys, *C*, *D*, and *E*, — the score *E* for the wire; the score *C* for a connecting rubber or rope band with the friction score of the reel, if desired; and the score *D* for an endless rope-band connecting with the hoisting-engine.

The accumulator is composed of the tubes *F*, *F*, *F*, and *C* (Figs. 4, 5), containing spiral springs (thirty-one inches long, two and a half inches outside diameter, four feet movement for one hundred and fifty pounds strain directly applied), connected with movable cross-head *H* (Fig. 5) by means of the chain (or wire rope) *I*, *I* (Figs. 4, 5),

which pass over the pulleys *J*, *J* (Figs. 4, 5). The tubes are hinged at *K*, *K* (Figs. 4, 5), so that the upper sections may be lowered for convenient stowage. They are graduated for the number of pounds pull on the wire, the upper arm of the cross-head being the index. The cross-head *H*, containing the pulley *L* (Fig. 4), moves on the guides *M*, *M* (Fig. 5), which are screwed to the tubes. The pulley *L* is rigidly attached to its axle by a key. To the axle is attached an odometer, *N* (Fig. 5). The pulley is exactly one yard (half-fathom) in circumference on the face, less the allowance for thickness of wire. One half the number of revolutions shown by the odometer will therefore give the number of fathoms of wire payed out or reeled in.

The object of the swivel pulley, *S* (Figs. 4, 5), is to allow for the reeling in of the wire while the vessel is steaming ahead.

The scales *W*, *X* (Fig. 4), should be of the kind that have a long movement of the pointer for a slight extension of the springs in the scales. In paying out the wire the difference between the readings of the scales *X* and *W* will be the number of pounds of resistance applied to the reel by the friction-rope. The wire to be used is the same as that recommended by Sir William Thomson, namely, steel piano-forte wire, No. 22, Birmingham gauge, weighing fourteen and a half pounds to the nautical mile. The friction-line should be a quarter of an inch or slightly less in diameter, and should be oiled or kept wet with water where it comes in contact with the friction-score of the reel. The weight is attached to a stray line, to prevent kinking when it reaches the bottom. In taking a sounding with the machine, allow the reel at first to revolve slowly until assured that everything is working well, then ease up the friction-line and follow out as nearly as practicable the rule governing the amount of resistance to be applied to the reel, which should be, as is stated by Thomson, always more than enough to balance the weight of wire out. It is impossible to say how fast the wire may be allowed to pay out, since the limit of safety varies with circumstances, and depends on the state of the sea and the extent and rapidity of the ship's rolling and pitching motions.

As soon as the sinker strikes bottom, which is made apparent by the stopping of the reel, read the register and the odometer, and at the same time ship the crank on the axles of the reel, and, to insure the detachment of the sinker, pay out a few turns

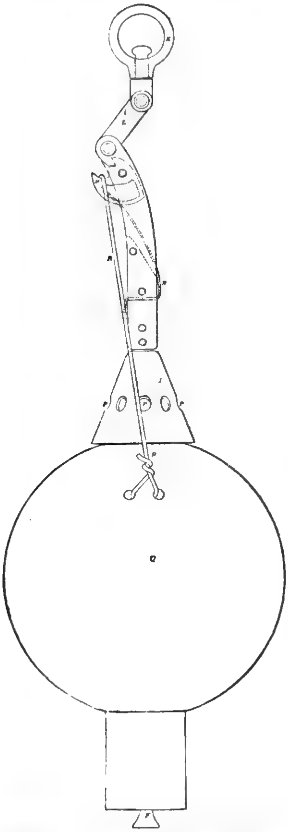


Fig. 6. — Sigsbee's Detacher, and Belknap's Sounding Cylinder. (Sigsbee.)

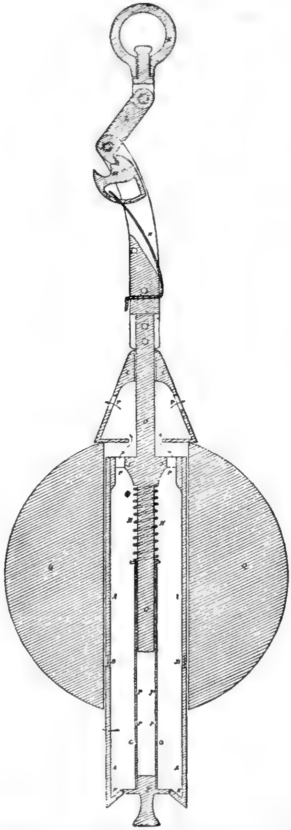


Fig. 7. — Section of Fig. 6. (Sigsbee.)

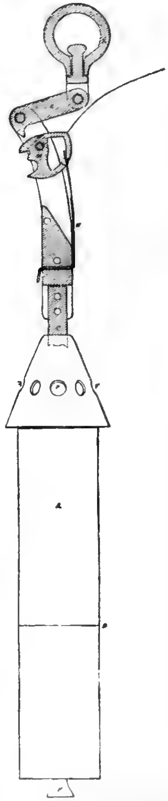


Fig. 8. — Belknap's Cylinder detached from Shot. (Sigsbee.)

of the wire by hand, until it feels slack. Then reel in a few turns, and the distance that the cross-head travels down its guides will indicate if the sinker has been detached. Generally, with a good form of detacher, it drops off on striking bottom. In place of the Stellwagen cup, rod, and detacher, used in Fig. 4, we may use for deeper soundings the sounding-rod, composed of Sigsbee's detacher in connection with a modification of Commander Belknap's cylinder No. 2. During the descent the cone *I* is kept up by the shot, as shown in Figs. 6 and 7,

and on striking bottom the bail is prevented from getting over the top of the detacher by the bearing which the sinker has against the under part of the cone.

When the sinker strikes bottom the slacking of the sounding-line or wire trips the tumbler, and the sinker is free to slide off the cylinder. This tumbler is kept back by the spring *N*, and the bail cannot be rehooked when the line is hauled taut to reel in. The resistance of the bottom soil raises the poppet-valve *F*, and the specimen of the bottom enters the cylinder, the water within the cylinder being free to escape through the various perforations *P*, *P*, etc. On hauling back the poppet-valve falls, or is forced by its spring, *H*, to the valve-seat, and the cone *I* falls, closing the water apertures. When the rod has been got on deck the lower part of the cylinder is unscrewed, when the specimen of soil may be extracted. To prevent the wire from coiling on the bottom, a piece of rope somewhat less than quarter of an inch in diameter, and from nine to twelve fathoms long (the stray line), is spliced to the wire, and to this is attached the sinker, detacher, and any instrument sent down while making a sounding.

The great advantage of sounding with wire is in the very great strength of the wire as compared with that of stout cod-line; also in the smoothness of its surface, by which the friction is reduced to a minimum; so that a wire weighing, say, twelve pounds in water to the mile, can readily take down a hundred-pound shot, and not only bring up the fourteen pounds weight of the sinker and collecting cylinder, but carry besides the thermometers needed to ascertain the temperature both of the bottom, and of intermediate depths as well. It would, however, in practice be more convenient to use a separate reel, and wire slightly heavier for making the temperature observations, and for having the water-cups attached.

The weight of the wire payed out in the deepest soundings yet made, 4,655 fathoms, will, in water, be less than sixty pounds, so that the weight of the sinker (one hundred pounds or more) can always be made to exceed that of the wire, an impossibility in the case of soundings made with hemp-lines. So far as accuracy is concerned, everything also is in favor of the wire method. The time of striking bottom is determined, not as in the case of

the hemp-line soundings by the great diminution of speed in the running out of the rope after the sinker has struck, but by the instantaneous action of the sinker on the wire when striking bottom; the wire stops, and in less than a second the momentum of the reel is checked by the friction-rope attached to it. The dropping of the shot is detected on deck with as great certainty as if it had been followed by the eye to the very bottom; indeed, the percentage of error in soundings made with piano-wire is probably not more than one fourth of one per cent. The error in soundings made by the old methods can only be determined after the rope-soundings have been corrected by wire-soundings. To those who are not familiar with the practical working of deep-sea soundings as formerly carried on, a few figures enabling them to compare the old with the new methods may be interesting. In the "Challenger" the deep-sea soundings were made with a rope of eight tenths of an inch in circumference, nearly as large as the steel-wire rope which we used in dredging, and having a breaking weight of 1,200 pounds. The time occupied in lowering the sounding machine and its weights, often more than 300 pounds, was three to four times as great as on the "Blake." We employed a steel wire (No. 20, American gauge), with breaking weight of 240 pounds, weighted for the deepest soundings only, with a sixty-pound shot. The time required to reel in with Captain Sigsbee's wire machine was generally below one minute and a half per one hundred fathoms, sometimes not more than fifty seconds, while the time required to strike bottom averaged from fifty to seventy-five seconds per one hundred fathoms in the deepest soundings up to two thousand fathoms. In depths less than one thousand fathoms or so, an ordinary thirty-four pound lead with a Stellwagen cup for obtaining bottom specimens was used. The lead was reeled in

Fig. 9. — Comparative Size of Hemp and Wire used for Sounding. (Sigsbee.)

Fig. 10. Sounding Lead with Stellwagen Cup. (Sigsbee.)

again and not detached; the speed of the reel was not quite so rapid, as will be seen on making a comparison of the following records, the one showing a sounding with a thirty-four pound lead, the other with a cannon-ball detached on striking bottom.

U. S. Coast Survey Steamer "Blake." Locality, twenty miles N.W. of Sombrero Island. Date, April 23, 1879. *Sounding, No.* 25. *Line PP. Sinker used, shot; weight,* 60 *lbs. Steel wire used,* 0.028″ *in diameter; weighs* 14.5 *lbs. to the nautical mile; breaking strain,* 240 *lbs.*

Turns of Reel as per Register.	Reeling out.		Reeling in.	
	Times.	Intervals.	Times.	Intervals.
	H. M. S.	M. S.	H. M. S.	M. S.
000	11 21 32	00	12 30 20	55
100	22 34	1 2	29 35	47
200	23 25	51	28 38	47
300	24 15	50	27 51	49
400	25 6	51	27 2	54
500	25 58	52	26 8	54
600	26 52	54	25 14	59
700	27 46	54	24 15	1 1
800	28 43	57	23 14	1 4
900	29 43	1 00	22 10	1 3
1000	30 41	58	21 7	1 7
1100	31 43	1 2	20 00	1 10
1200	32 46	1 3	18 50	1 10
1300	33 48	1 2	17 40	1 13
1400	34 54	1 6	16 27	1 18
1500	36 1	1 7	15 9	1 18
1600	37 9	1 8	13 51	1 21
1700	38 15	1 6	12 30	1 23
1800	39 26	1 11	11 7	1 24
1900	40 35	1 9	9 43	1 25
2000	41 48	1 13	8 18	1 25
2100	43 2	1 14	6 53	1 37
2200	44 11	1 9	5 16	1 34
2300	45 24	1 13	3 42	1 38
2400	46 38	1 14	2 4	1 31
2500	47 53	1 15	12 00 33	1 56
2600	49 8	1 15	58 37	1 53
2700	50 24	1 16	56 44	59
2765	11 51 17	53	11 55 45	
2900				
3000				
Totals . . .	. . . .	29 45 [1]	. . . .	34 35 [1]

Reading of Register	2,765 turns.
Correction for stray line	6
Correction for turns of wire	158
Correct depth	2,929 fathoms.

[1] The time intervals are slower than the average, but this record is given as one of the deepest soundings made with wire at the time it was taken.

U. S. Coast Survey Steamer "Blake." Locality, off Grenada. Date, March 2, 1879. *Sounding No.* 37. *Line K. Sinker used, lead; weight,* 34 *lbs.*

Turns of Reel as per Register.	Reeling out.		Reeling in.	
	Times.	Intervals.	Times.	Intervals.
	H. M. S.	M. S.	H. M. S.	M. S.
000	4 20 45	00	4 43 30	1 00
100	21 42	57	42 30	46
200	22 35	53	41 44	43
300	23 35	1 00	41 1	49
400	24 30	55	40 12	50
500	25 32	1 2	39 22	1 4
600	26 40	1 8	38 18	1 3
700	27 50	1 10	37 15	1 13
800	29 25	1 35	36 2	1 3
875	4 30 35	1 10	4 34 59	
Totals . . .	. . .	9 50	. . .	8 31

Reading of Register	875 turns.
Correction for stray line	6
Correction for turns of wire	74
Correct depth	955 fathoms.

The time occupied in taking one of the most recent deep-sea soundings by the old methods (those of the "Challenger") is here given to show the comparative advantage of the two.

Hydra machine, weight 336 *lbs. Weight of line,* 12 *lbs.* 8 *oz. per* 100 *fms.; breaking strain,* 1,200 *lbs.; circumference,* 0.8″.

Fathoms.	Time.	Intervals.	Fathoms.	Time.	Intervals.
	H. M. S.	M. S.		H. M. S.	M. S.
000	2 44 20	00	1300	2 58 5	1 23
100	2 45 5	45	1400	2 59 37	1 32
200	2 45 45	40	1500	3 1 9	1 32
300	2 46 30	45	1600	3 2 42	1 33
400	2 47 25	55	1700	3 4 19	1 37
500	2 48 15	50	1800	3 6 6	1 47
600	2 49 15	1 00	1900	3 7 53	1 47
700	2 50 24	1 9	2000	3 9 40	1 47
800	2 51 23	59	2100	3 11 29	1 49
900	2 52 45	1 22	2200	3 13 24	1 55
1000	2 54 00	1 15	2300	3 15 23	1 59
1100	2 55 21	1 21	2400	3 17 15	1 52
1200	2 56 42	1 21	2435	3 17 55	40

The whole time occupied in descent was thirty-three minutes, thirty-five seconds; and in heaving up, two hours, two minutes!

Sir William Thomson would find it difficult indeed to recognize his original machine as now used on board the "Blake," with the modifications introduced by Lieutenant-Commander Sigsbee. During the four years of his command, the latter ran no less than 12,766 nautical miles of sounding-lines, with the necessary serial lines of temperatures. As the result of his magnificent work, the Coast Survey is publishing a hydrographic chart of the Gulf of Mexico, not merely unequalled for its accuracy, but unique as the first chart of any extent which carries the littoral hydrography to great depths.

The depth having been obtained, the thermometer attached to the stray line will, if allowed to remain long enough before it is drawn up, record the bottom temperature. The deep-sea thermometer used is known as the Miller-Casella. (Fig. 11.) It is a maximum and minimum thermometer. Its modified form was suggested by Professor Miller, and constructed by Casella. It consists of a U-shaped tube, the lower part of which is filled with mercury, the U terminating on the one side in a large bulb filled with a mixture of creosote and water, while the small bulb of the other branch is filled only in part with the same liquid. A steel index, kept in place by a horse-hair spring, is placed in each limb. The indications are given by the expansion and contraction of the mixture in the large bulb, which allows the mercury either to recede from the large bulb or to flow towards it; the index is carried on either side by the movement of the mercury, and on the retreat of the mercury the index remains at the highest point reached. To prevent the effects of the enormous pressures to which these thermometers are subject, the inner large bulb is protected by an outer bulb nearly filled with alcohol,

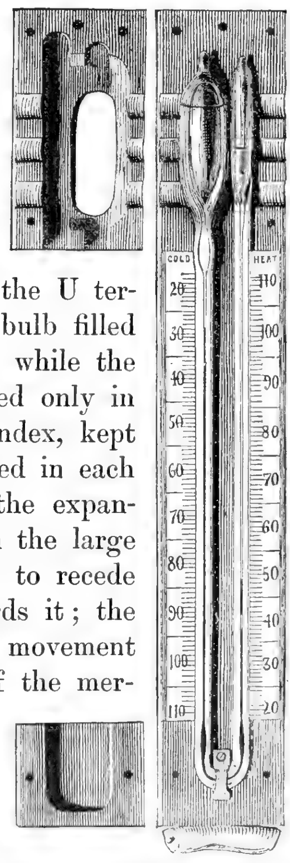


Fig. 11. — Miller-Casella Thermometer. Half size.

space enough being left for the compression of the outer bulb. The correction of each thermometer for pressure is ascertained by experiment.[1]

A great objection to the use of the Miller-Casella for obtaining deep-sea temperatures is found in the fact that they will register only the lowest temperature obtained. The most common form of deep-sea thermometer now in use is a modification of Negretti and Zambra's instrument, of which a figure is here given; the propeller is constructed on the same principle as that of the Sigsbee water-cup, and holds the thermometer with the bulb (*b*) downward till the line is drawn up. On being freed from the stopper (*f*) the thermometer assumes the position given in the figure, and the column of mercury which has become freed from the bulb by the tilting on the axis (*p*) indicates the temperature at the point where it was turned over. When temperatures are taken in a district where they diminish gradually from the surface to the bottom, as is generally the case in the tropics, this defect is not of great consequence. When, however, we seek to ascertain the temperatures of the Gulf Stream, or to work in the Arctic regions, where the coldest water may be nearest the surface, we are unable, of course, to determine the position of the coldest or warmest intermediate layers of water. The only perfect method of taking serial temperatures is one which records them continuously on deck during

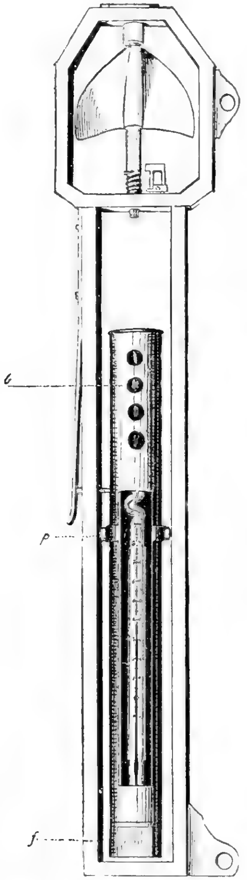


Fig. 12. — Negretti-Zambra Thermometer, Italian model.

[1] Professor Tait, who has made an exhaustive investigation of the corrections to be applied to the deep-sea thermometers of the "Challenger," came to the conclusion that the only cause which is active in affecting them when let down into the sea is pressure, and that the correction to be applied to them is that given by Captain Davis and Professor Miller, of somewhat less than half a degree Fahrenheit for every mile under the sea.

the descent of the thermometer. Such an apparatus has been devised by Sir William Siemens. In the Bakerian Lecture for 1871, he showed that the principle of the variation with the temperature of the electrical resistance of a conductor might be applied to the construction of a thermometer, which would be of use in cases where a mercurial thermometer was not available. The instrument he described has since been largely used as a pyrometer for determining the temperatures of hot blasts and smelting furnaces; and it has been found that its indications agree very closely with those of an air-thermometer. He devised a similar instrument for measuring temperatures where a much greater degree of accuracy is required, as in the case of deep-sea observations; and during the autumn of 1881, this deep-sea electric thermometer was subjected to a series of tests on board the "Blake," by Commander Bartlett.

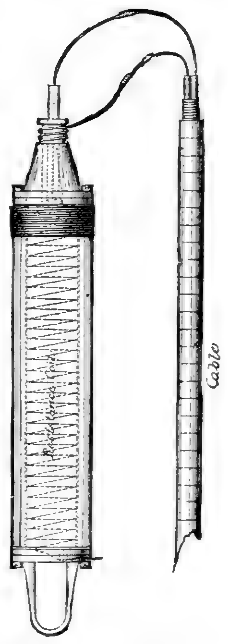


Fig. 13.—Siemens's Sinker and Resistance Coil. (Bartlett, U. S. Coast Survey.)

The apparatus consists essentially of a coil of silk-covered iron-wire (Fig. 13), fifteen millimetres diameter, and about four hundred and thirty-two ohms resistance, attached to an insulated cable by which it can be lowered to the required depth, and connected so as to form one arm of a Wheatstone bridge. The corresponding arm of the bridge is formed by a second coil, made precisely similar to the former one and of equal resistance. This coil is immersed in a copper vessel filled with water, and the temperature of the water is adjusted by adding iced or hot water until the bridge is balanced. The temperature of the water in the vessel is then read by a mercurial thermometer, and corresponds with the temperature of the resistance-coil.

To avoid the error which would otherwise be introduced by the leads of the resistance-coil, the cable is constructed of a double core of insulated copper-wire, protected by twisted galvanized steel-wire. One of the copper cores is connected with

each arm of the bridge, and the steel-wire serves as the return earth connection for both. Sir William Thomson's marine galvanometer, with a mirror and scale, is employed to determine the balance of the bridge. (Fig. 14.)

The apparatus was set up on board the "Blake" in April, 1881, and experiments were made off the east coast during

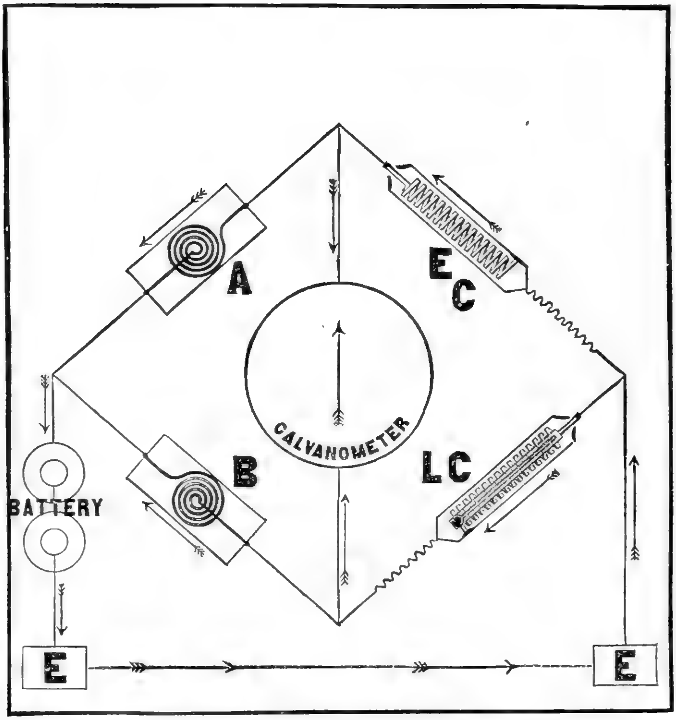


Fig. 14. — Wheatstone's Bridge. (Bartlett, U. S. Coast Survey.)

August. In each series of experiments the temperatures at different depths were first taken by Miller-Casella thermometers attached to a sounding-wire. A sinker was then fastened to the resistance-coil, and it was lowered by the cable to the same depths, when the temperature was read by means of the mercurial thermometer attached to the comparison-coil. The depths at which readings were taken ranged from the surface down to eight hundred fathoms, and experiments were made in both rough and still water. The temperatures recorded varied from 38.5° to 81.5° F. In every case the readings of the electrical

instrument were precisely the same as those of the Miller-Casella thermometers for the surface and the maximum depth; but for intermediate positions, it was observed that the electrical thermometer in almost every case gave a slightly higher reading. This discrepancy may be accounted for, Sir William Siemens thinks, by the fact that the electrical thermometer gives the

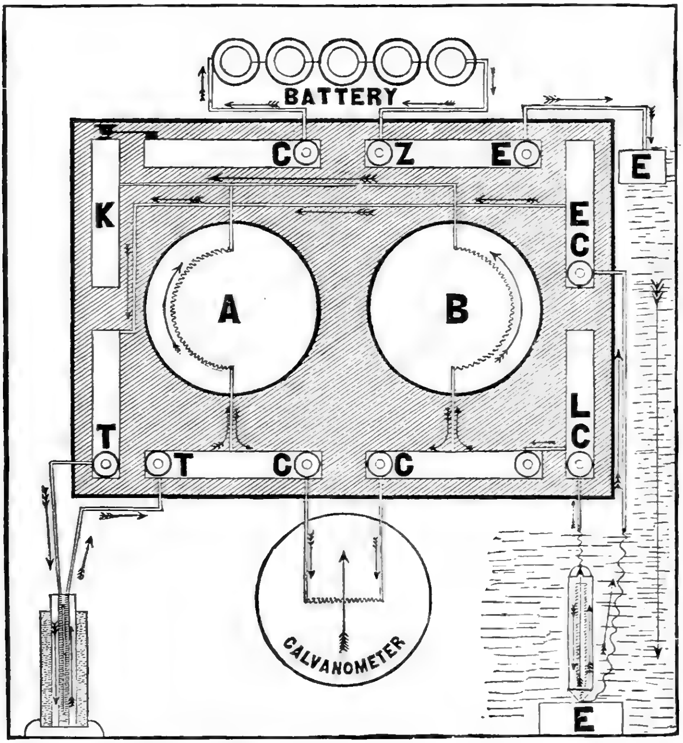


Fig. 15.—C. W. Siemens's Deep-Sea Thermometer. (Bartlett, U. S. Coast Survey.)

temperature of the water actually surrounding the coil at the moment of observation, whereas the Miller-Casella instrument brings to the surface, or at least its readings are affected by, the maximum or minimum temperatures encountered in its ascent or descent, which may not coincide with that at the point of stoppage. This furnishes a very strong argument in favor of the superior accuracy of the electrical instrument. (Fig. 15.)

It was found that about five minutes must be allowed at each observation for the resistance-coil to assume the temperature of

the water surrounding it, and a second period of five minutes for adjusting the temperature of the comparison-coil on deck. Allowing five minutes more for lowering the cable, fifteen minutes sufficed to complete a deep-sea observation.

The instrument was sufficiently tested by Commander Bartlett, during the season of 1881, to show its entire practicability. The accompanying table is taken from his Report to Professor J. E. Hilgard, the superintendent of the United States Coast Survey: —

Depth in Fathoms.	Siemens.	Miller-Casella.
Surface	$77\frac{1}{2}$	$77\frac{1}{2}$
5 fathoms	$76\frac{1}{4}$	$75\frac{1}{4}$
10 "	$75\frac{1}{4}$	69 [1]
15 "	$66\frac{1}{2}$	$63\frac{1}{2}$ [1]
20 "	58	57 [1]
30 "	$51\frac{1}{2}$	$51\frac{1}{2}$
50 "	$54\frac{1}{2}$	$52\frac{1}{2}$
75 "	$53\frac{1}{2}$	$53\frac{1}{2}$
100 "	51	$49\frac{1}{2}$
125 "	$48\frac{1}{4}$	
150 "	$46\frac{1}{4}$	46
200 "	$43\frac{1}{2}$	$43\frac{1}{4}$
300 "	$40\frac{1}{2}$	$40\frac{3}{4}$
400 "	40	$39\frac{3}{4}$
500 "	$39\frac{1}{4}$	39
600 "	$38\frac{3}{4}$	$38\frac{3}{4}$
700 "	$38\frac{1}{2}$	$38\frac{1}{2}$
800 "	$38\frac{1}{2}$	$38\frac{1}{2}$

Much yet remains to be done before we can ascertain accurately not only the force, but also the direction of the currents, at different depths, from the surface to the bottom; the floats usually employed to make these observations are rather primitive instruments. Here also we must look to electricity for the means of making simultaneous or continuous observations.

The specific gravity of the sea-water was determined on the "Blake" by means of an apparatus devised by Professor J. E. Hilgard (Fig. 16) of the Coast Survey. As the differences of density are very small, the instrument must be one of great delicacy; it is constructed upon the same principle as that of

[1] According to Commander Bartlett, the Siemens apparatus recorded the presence of a warm belt between 10 and 30 fathoms, which was not detected by the Miller-Casella, indicating only maxima and minima.

an ordinary aerometer. The specific gravity could also be determined, as has been suggested by Professor Wolcott Gibbs, by observing the index of refraction of the different samples of sea-water.

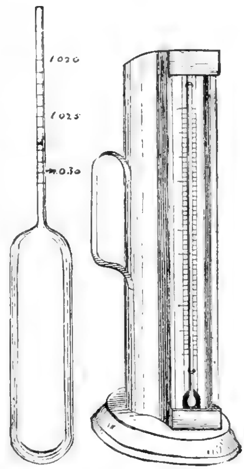


Fig. 16. — Hilgard Salinometer. (Sigsbee.)

Some of the most interesting problems of biology are dependent for their solution upon an accurate knowledge of the physics of the salt water at the great depths from which animal life has been brought up. In order to analyze with accuracy the water brought from the bottom, the cup in which it is conveyed to the surface must be so hermetically closed as not to allow any admixture of water from intermediate depths, or any escape of the gases during the upward passage of the water-cup. The water-cups thus far employed for this purpose are rather rude instruments, and do not guard positively against these sources of error. Those in use on the "Blake" seem to be the simplest, and superior in efficiency and accuracy to any cups employed in the deep-sea explorations preceding ours; when once closed there is no danger of their opening again from the pitching of the vessel or the stopping of the upward motion. The propeller, which screws down the valves, from the time the regular upward movement of the bottle begins is, as it were, thrown out of gear, and cannot undo the work it has once performed. As the cup descends, the resistance of the water raises the valves, and also screws up the propeller until the lower thread in the hub clears the upper thread on the shaft, when the propeller uncouples and revolves freely on it; the blades of the propeller are bent on their upper edge. It has been found, experimentally, that with the blades thus bent, by rising and falling equal distances through the water the propeller will screw up instead of down. Without this bending it is evident that the propeller would gradually screw down by a rising and falling motion. At any stoppage each cup has within its cylinder a specimen of the water from the place where it stops. (Figs. 17, 18.)

On hauling in, the propeller of the cup screws down, by the resistance of the water, until the upper thread of the hub clears the lower thread of the corresponding screw on the shaft, when the propeller drops on the screw-cap; the lugs *R*, *R*, clutch into the slots *U*, *U*, and the screw-cap is screwed down until it touches the upper valve, which keeps both valves closed. The screw-cap is found screwed down so tight in coming out of the water that it can be set no tighter without endangering the thread.

The tests to which the water-cup has been submitted show that it closes in a depth of about ten to fifteen fathoms, and then remains hermetically sealed. For serial lines the water-bottles and thermometers were not sent down on the sounding-line, but a stronger steel cord, three eighths of an inch in circumference, was used, to which the thermometers and bottles were attached.

The annexed sketches of Sigsbee's water-bottle (Figs. 17, 18) will interest those who have used the older apparatus for obtaining water from great depth. The method of closing the valves is entirely different from that employed by other hydrographers.

Fig. 17 gives a view of Sigsbee's water-bottle, seen facing the frame of the propeller (*p*), by which the valves are closed.

Fig. 18 shows a section of the same bottle, and Fig. 19 the mode of attaching it to the steel rope by means of a spring devised by Lieutenant-Commander Sigsbee. This is done in an instant, and the bottles are firmly held in place by the double spring holding the rope at two points. The same mode of attachment has been adopted for securing the thermometers (Fig. 20) to the line or wire with the least possible delay, and for their easy detachment in place of the clumsy and tedious process of tying and untying them when a serial line of temperatures is to be made.

There was no attempt on our trips to make any chemical examination of the water brought up from different depths. The small size of the vessel made a chemical laboratory out of the question, and it seems more feasible for this purpose to establish

a laboratory on shore at some point near deep water, carrying the bottles to the laboratory for analysis.

A small chemical laboratory was fitted up on board the "Challenger," where the elements of the chemistry and physics

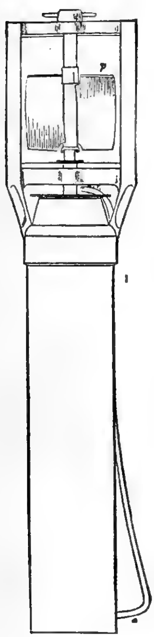


Fig. 17. — Sigsbee's Water-Cup. (Sigsbee.)

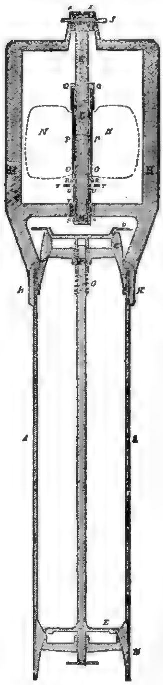


Fig. 18. — Section of Sigsbee's Water-Cup. (Sigsbee.)

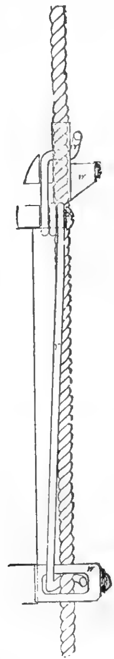


Fig. 19. — Mode of Attachment of Thermometer and Cups. (Sigsbee.)

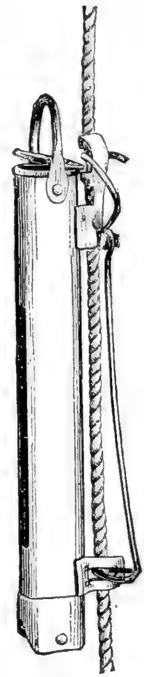


Fig. 20. — Miller-Casella Thermometer in Protecting Case, with Sigsbee's Attachment. (Sigsbee.)

of the water at the bottom of the oceans were worked out by Mr. Buchanan, the chemist of that expedition. From his analyses it appears that the amount of carbonic acid present in water taken from the bottom is much greater than in surface water, and that the amount of oxygen gas may be somewhat larger than at the surface.

The apparatus used for bringing up the animals living at great depths is very simple. Until recently, the dredge first used by a Danish naturalist, O. F. Müller in the last century,

had undergone but slight modifications. It consists of a rectangular frame with flattened sides, to which a bag of netting is attached, this again being protected by a canvas bag.

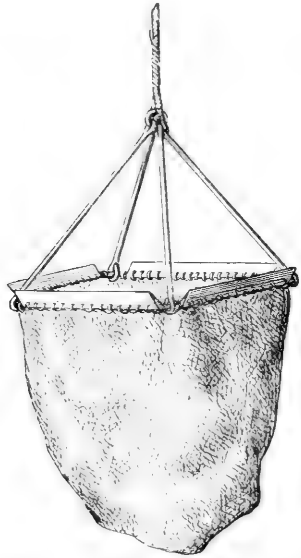


Fig. 21. — Müller's Dredge. (Thomson.)

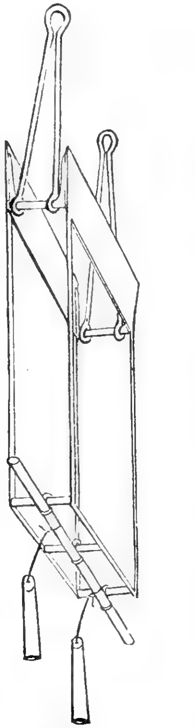


Fig. 22. — "Blake" Dredge Frame.

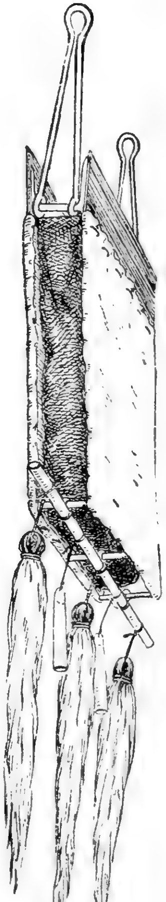


Fig. 23. "Blake" Dredge.

The dredging-rope is attached to one of the wire arms fastened to the short side of the dredge-frame; the other arm is made fast to the first by a stout marline, so that in case the dredge fouls, the marline will give way, trip the dredge, and not part the rope, which would involve the loss of the dredge. The dredges used in deep water are generally much larger and heavier than those used from small sail-boats. To prevent the crushing of delicate specimens by the dragging of the bag over rough bottoms, a frame-work (Fig. 22) has been added to the ordinary dredge; this is covered with heavy canvas (Fig. 23), so that the bag with its contents is relieved of the wear and tear which comes of dragging it over the bottom; the most delicate specimens are thus secured uninjured.

While using, especially on muddy bottom, the dredge as formerly made, with a frame having a bevelled edge, we experienced great annoyance at first from the amount of mud brought up by it. When the dredge was dropped in soft ooze, it evidently sank deeply in it and filled at once; and since the viscid mud did not wash out easily, it was even difficult to sift it on deck. To obviate this defect, we stopped a piece of two-and-a-half-inch rope below the dredge-frame to raise the lips and prevent it from cutting into the mud. This worked admirably, and after that our dredges always came up bringing less mud and a larger supply of specimens. We subsequently made our dredges with a flat frame, obviating completely the defects in the old-fashioned dredges.[1]

Attached to the end of the dredge-frame is a long iron bar to which are fastened large swabs. These huge rope tails trail behind the dredge, and in them become entangled all sorts of starfish, sea-urchins, crabs, corals, sea-fans, sponges, and even fishes which do not readily find their way into the dredge. When the bottom is very rough or rocky, or it is of uneven coral, the bar and tangles alone are frequently used. (Fig. 24.) For this sort of bottom, where there is always danger that either a dredge or a trawl may be carried

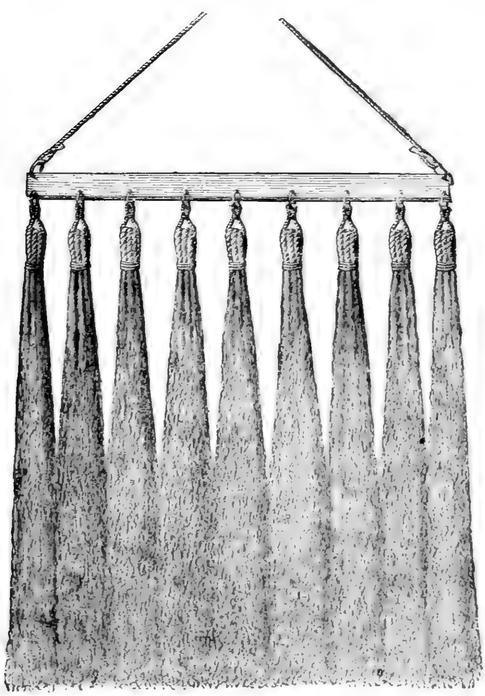


Fig. 24. — Bar and Tangles.

[1] A dredge is used among natives of the Philippines and Japan. Mr. Moseley has given a sketch of such a dredge in action in one of his lectures on Deep-Sea Dredging.

away, the bar and tangles, which may be composed of a dozen to fifteen bundles, afford perhaps the most effective apparatus for collecting. The amount of material sometimes brought up baffles description, and it is no easy task to separate the specimens from the tangled mass in which they have been caught.[1] The trawl is by far the most useful instrument in deeper water, where the bottom generally consists of ooze or fine mud, — the finer in proportion to the distance from land. The trawl first used in deep water was the ordinary beam-trawl of fishermen. When this form of trawl is used in shallow water, it is easy to guide it or to weight it so that it will always fall on its runners and drag successfully. At great depths, however, this form of trawl becomes objectionable, from the impossibility, owing to currents or the drift of the vessel, of guiding it, no matter how well-balanced it may be, so that it shall not land on the beam, a mishap that involves great waste of time, sometimes a whole day, from unsuccessful hauls. On the "Blake," a modification of the trawl was used (Figs. 25, 26), which worked admira-

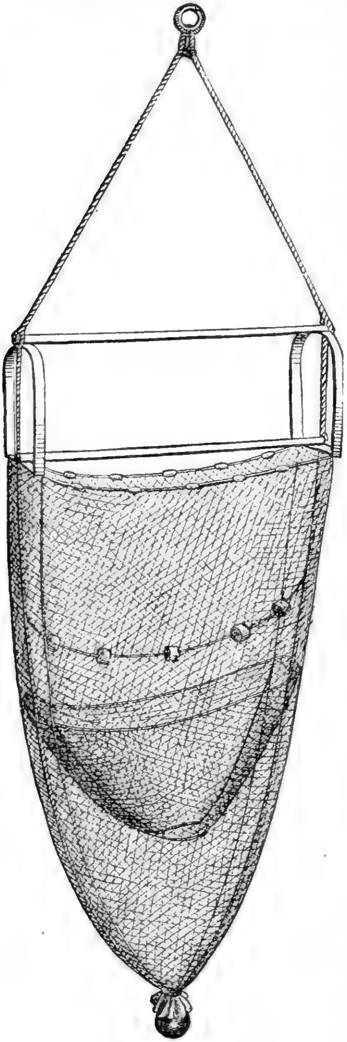


Fig. 26. — "Blake" Trawl.

[1] A tangle-bar of great efficiency, consisting of two poles tied in the form of the letter A, with cross-bar and lines with fishing-hooks, has been used with great success by Mr. Marshall, to collect halcyonoids. A very similar apparatus is also used by the natives of the Philippines to collect euplectella.

The members of the United States Fish Commission have also introduced a number of admirable modifications of dredges, trawls, tangles, and sieves; and, in fact, every part of the dredging apparatus now necessary for deep-sea work has been greatly improved by the experience obtained during more than ten

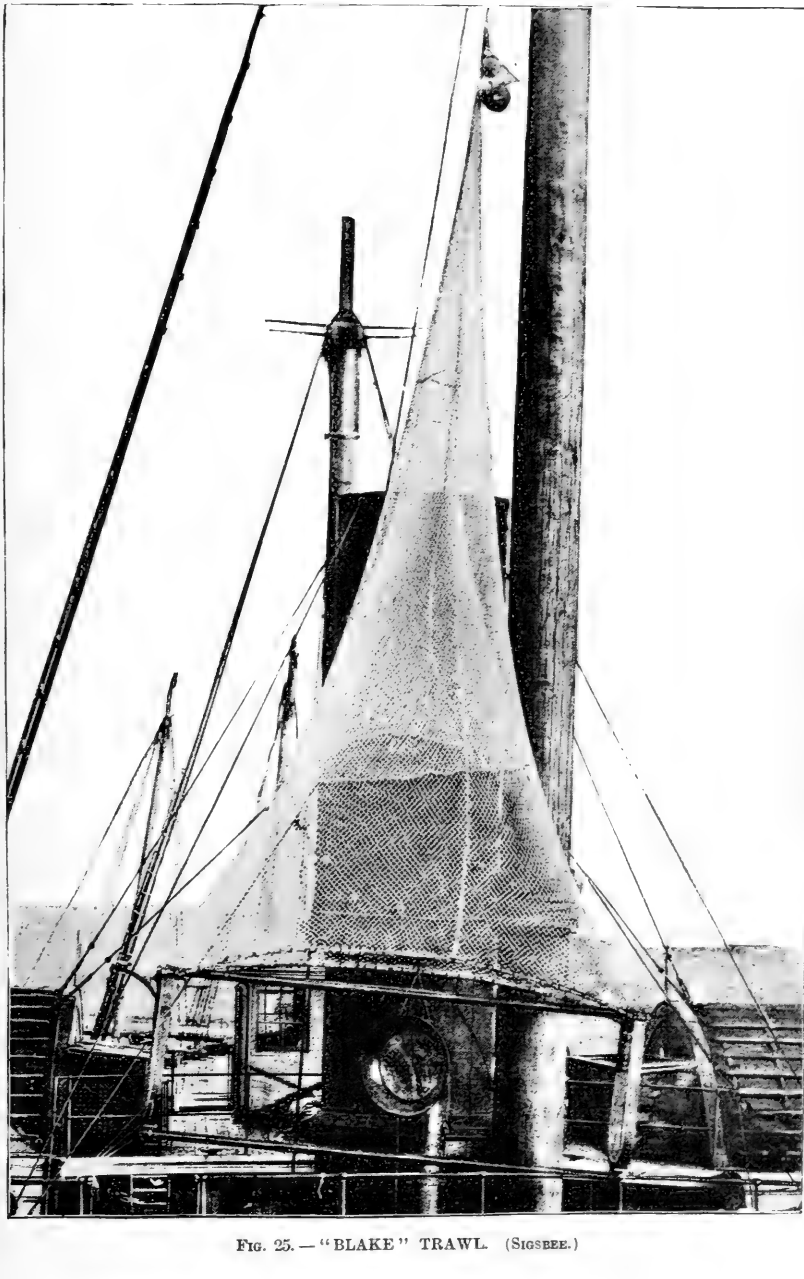


Fig. 25. — "BLAKE" TRAWL. (Sigsbee.)

bly, obviating all fouling, and doing away with the frequent delays so annoying when the ordinary single-beam trawl is used in deep water. It was practically a double trawl, bearing the same relation to the old beam-trawl which the ordinary dredges bear to the old oyster dredge, and sure to do its duty, on whatever side it might happen to fall; the runners were made elliptical, high enough to give fair scope to the lead line of the trawl, and thus it became a matter of indifference on which side of the runners the trawl landed. Under these conditions the hauls were always successful.

At great depths, where a light ooze covers the bottom, the trawl soon becomes completely filled with the mass of sticky mud which finds its way into it; and when brought to the surface it is found that but little has been washed out through the meshes of the trawl-bag. The labor of sifting this large mass of mud (often as much as a ton) is very considerable. It is done by washing off the mud in sieves provided with handles, and shaken in tubs of water. The United States Fish Commission use a table-sieve upon which plays a hose; this quickly disposes of a large amount of mud. It became important to do the sifting as far as practicable while trawling. To accomplish this, the bag of the trawl was greatly shortened (reduced to fifteen feet), and the meshes of the outer net made coarse, while only a very small part of the bag was fine enough to allow the accumulation of mud. The result proved the wisdom of this change. We were now rarely overwhelmed with the masses of mud which had rendered so much additional work of sifting necessary during the first cruises. After this change it also became possible to drag the trawl with considerable rapidity over the bottom (sometimes as fast as three and one-half miles an hour), and thus to catch the more active fishes and crustacea, which keep out of the way of the trawl when it moves slowly. We also tried dragging a heavy tow-net rapidly over the ground at great depths, in hopes of accomplishing the same object; but we found that, after all, no deep-sea machine worked

years of dredging and sounding off the coast of the United States in the "Fish Hawk" and "Albatross." A full account of the apparatus will be found in the Annual Reports of the United States Fish Commission.

better than a trawl, which, when moved rapidly over the ground, at the rate sometimes of two to two and a half miles an hour, invariably brought up a fine harvest of fishes and crustacea, in addition to the usual contents of the sedentary and more sluggish forms. Although the deep-sea tow-net was used several times, we never brought up any of the so-called deep-sea siphonophores of Studer, even in localities where they came up on the wire rope.

All dredging expeditions previous to the first cruise of the "Blake" had used best selected hemp rope for dredging.[1] The objections, already mentioned, to the use of hemp rope, speaking of sounding, apply with even greater force to its use in dredging. The necessity of loading down the trawl with weights, or of making the trawl itself enormously heavy, in

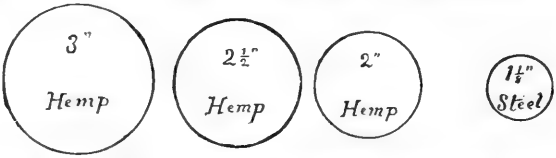


Fig. 27. — Comparative Size of Dredging-Ropes. (Sigsbee.)

order to sink a heavy rope strong enough to bring back not only its own weight, but that of the trawl and its contents and of the weights usually sent down with the dredge, — all this increased the danger that the rope might part at great depths. The rope also, after short use in deep water, becomes very brittle from the great pressure to which it has been subjected, and unfit to bear any considerable strain. My familiarity with the successful use of very long steel ropes for mining purposes naturally suggested their adaptation to the new purpose of deep-sea work. The results anticipated have been fully realized, and the gains in space (Fig. 27), in time,[2] in safety and facility

[1] The rope used for deep dredging is usually two and one half inches in circumference. It weighs two pounds to the fathom, breaking strain about two tons; so that the weight of rope, trawl, and contents is often more than half the breaking strain.

[2] A haul of the trawl was frequently made by the "Blake," in fifteen hundred fathoms, in less than two hours and three quarters, dragging on the bottom twenty-five minutes. The trawl can safely be lowered at the rate of one hundred fathoms in four minutes, and be reeled in at the same or even a more rapid rate.

of work, and finally in expense, have made deep-sea dredging a possibility on comparatively small vessels. It would have been difficult, if not impossible, on a small vessel of the size of the "Blake" (of only three hundred and fifty tons burthen) to make provision for the equipment of hemp rope necessary for a season of dredging at the depths in which we usually worked in the Gulf of Mexico. Our stock of steel rope was only six thousand fathoms. The loss of rope was trifling, and much of the original steel rope, after three years of constant use during two previous cruises, was still available during the third cruise.

The wire rope we used was of galvanized steel with a hemp core; it measured one and one eighth inches in circumference, weighing one pound to the fathom, with a breaking strain of over eighty-six hundred pounds, as tested by the Roebling & Sons' Company, the manufacturers. We took with us only two coils, each of three thousand fathoms. One coil was on deck, wound to an iron reel and frame provided with a friction-brake for lowering the dredge or trawl, the whole space occupied by this length of rope on the reel being only five feet long, four feet wide, and five feet high. In addition to the economy of space thus gained, we were enabled to dispense with sending down heavy weights to drag in front of the dredge at a distance from the frame, as was invariably done by the "Challenger," the weight of the steel rope in water rendering this unnecessary. Our greatest gain from the use of steel-wire rope came from the rapidity with which we could lower and hoist the dredge. In fact, this was done as rapidly as is customary in lowering or hoisting skips on the slope of a mine. Our usual speed in lowering the dredge, until it came within a few fathoms of the bottom, was between two and a half and three minutes for a hundred fathoms, when we lowered more carefully, and then payed out the slack very gradually, the dredge dragging on the bottom all the time. In bringing it up after the dredge was clear of the bottom, we hoisted again at the same speed, and as far as I could perceive the specimens were none the worse for their rapid upward journey. This gave us a chance to make several hauls a day, and by not leaving the

dredge or trawl to drag too long on the bottom we obviated the great loss of time due to fouling, reversing, or any other accident out of sight. In the "Challenger" the best part of the day was generally consumed in making a haul at a depth of fifteen hundred fathoms. We experienced no inconvenience from the kinking of the rope, if it was kept well stretched, and not allowed to lie slack on the bottom. The uniform success attending the use of this rope during our dredging seasons enables me to recommend it to any future deep-sea dredging expedition, as insuring an economy of space, time, and money; for the rope occupied about one ninth of the space required by a hemp rope, and was, at the end of the cruise, as good as when we first left Key West.

Not the least superiority of the steel rope over the hemp rope is its power of telephoning, as it were, from the bottom. By keeping hold of the wire rope on deck, the least movement of the dredge or trawl on the bottom is transmitted with absolute certainty, and it soon becomes an easy matter for the officer in charge of the dredging not only to tell whether the trawl is dragging well, but also the kind of bottom over which it is passing. The vibrations of the rope when the trawl passes over a gravelly, or a sandy, or a smooth, muddy bottom are all characteristic and in strong contrast with those produced by the quick jumps of the trawl over a rough and slightly rocky bottom. The movements of the dredge are repeated by the vibrations of the steel rope so promptly that the moment it pulls or passes over rough bottom the speed of the vessel can at once be checked, or its direction altered, before the tension is great enough to affect the accumulator.

Heavy strains on the line can be detected in the same manner, and for greater safety an accumulator is connected with the pulley over which the wire rope leads to the bow of the vessel at the end of the dredging-boom. This accumulator (Fig. 28) is made up of a series of india-rubber car-springs, suspended along the foremast and kept in place by iron guides. These are compressed by a strain, and expand again into their natural position when the pressure is taken off. The amount of compression indicates the care to be taken in handling the trawl

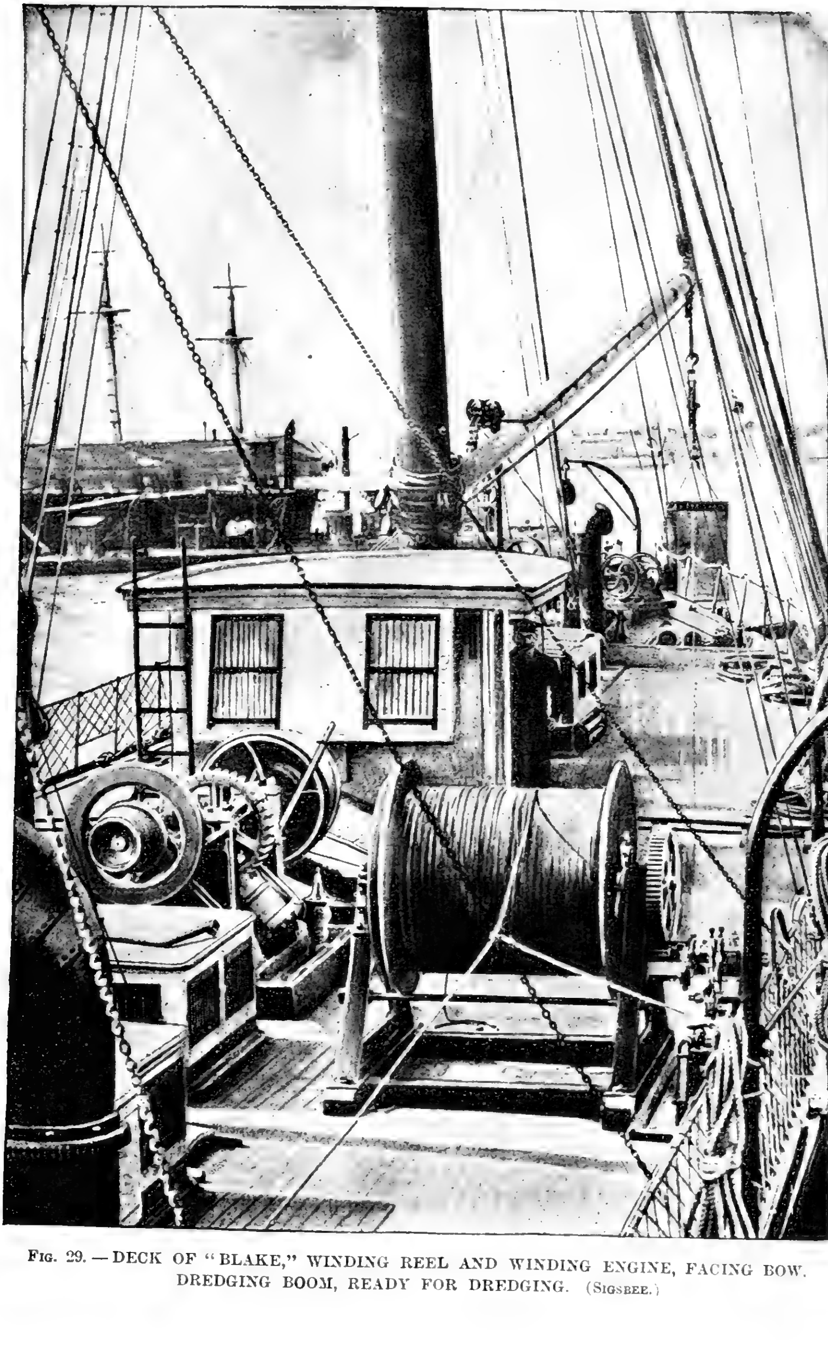


Fig. 29. — DECK OF "BLAKE," WINDING REEL AND WINDING ENGINE, FACING BOW. DREDGING BOOM, READY FOR DREDGING. (Sigsbee.)

when there is a great weight in it, or when the vessel is pitching. The curve made by the wire rope, as it leads from the vessel to the trawl, is of itself the best accumulator, as a comparatively slight strain will constantly tend to change the form of the catenary. It is only while hoisting the dredge that the accumulator is useful, and long before it works to its full power the changes of form of the catenary of the wire rope, from an easy winding in of the dredge to the fouling of the same, will produce a greater or less strain, entirely unnoticed, on the accumulator, if (as in our case) the strain is less than two thousand pounds. The friction of the steel rope against the wire, even when two or three thousand fathoms of wire are out, is far less than the breaking weight (eighty-six hundred pounds) of the steel-wire rope (one and one eighth inches circumference) used on the "Blake."

Fig. 28.—Accumulator. (Sigsbee.)

The steel rope was hoisted by a small double-cylinder winding-engine, with a surging-drum, from which the rope then passed to the reel, where it was coiled as closely as practicable. The reel was managed by a pair of small engines used to wind the line, and by a friction-brake when the rope was lowered.

In dredging, the dredge or trawl was invariably lowered independently of the winding-engine, from a reel built especially for the work. This reel, built of iron, consisted of a hollow axle two feet in diameter, four feet long, flanked by flanges extending eighteen inches above it, capable of winding about four thousand fathoms of one and one eighth inches steel-wire rope. The axle upon which the reel ran was supported upon bearings carried upon a strong iron frame securely bolted to the deck; the reel was checked by a band friction-brake, by which one man could readily control the velocity of the steel rope as it was unwound and could accurately regulate the speed. The brake was of sufficient strength to stop the dredge even at a depth of nearly two thousand fathoms; and while dredging or trawling, the brake

was securely held in place, and the dredging carried on from it. To wind up, the wire rope was stopped and sufficient slack taken from the reel to make the necessary turns round the surging-drum of the hoisting-engine. When this was done the reel was made taut, the stops were unfastened, and the wire rope was wound up by the winding-engine until the dredge came in sight.

During the whole time the dredge or trawl was lowered or hoisted, the recorders kept an accurate record of the time spent in paying out or reeling in the rope, so that at any moment we knew the precise position of the dredge and the quantity of rope still out.

The uniform success which attended all our hauls was undoubtedly due not only to the improvements suggested in the apparatus by Lieutenant-Commander Sigsbee, by Lieutenant-Commanding Ackley, by Lieutenant Sharrer, and by Messrs. Jacoby and Moore, but also to the great care taken by the officer of the deck in handling the "Blake" during the progress of a haul.[1] With a vessel of the size of the "Blake," excellent judgment was necessary while working in a seaway, and that we incurred so few accidents is entirely due to the interest taken in the expedition by the officers, and the devices constantly suggested by them for overcoming the difficulties we encountered in this novel work.

The strain of the trawl is taken up directly by the reeling-engine; this has a surging-drum round which the wire rope passes eight or ten times, the wire reel becoming a mere spool relieved of all pressure, either in winding or in dredging, by the surging-drum of the winding-engine. This drum is a fathom in circumference, and, being connected with an indicator, the amount of rope out can always be accurately read on the dial. A similar arrangement exists for measuring the sounding-wire; but as the wire piles on the reel, a slight correction must be applied in that case to determine the exact length of wire payed out.

[1] The other officers of the "Blake" were Lieutenants Wallis and Mentz, Master McCrea, and Ensigns Peters and Reynolds. Mr. Pemberton was the engineer during the other dredging cruises of the "Blake;" Dr. Nourse, Dr. Persons, and Mr. L. P. Sigsbee served as recorders.

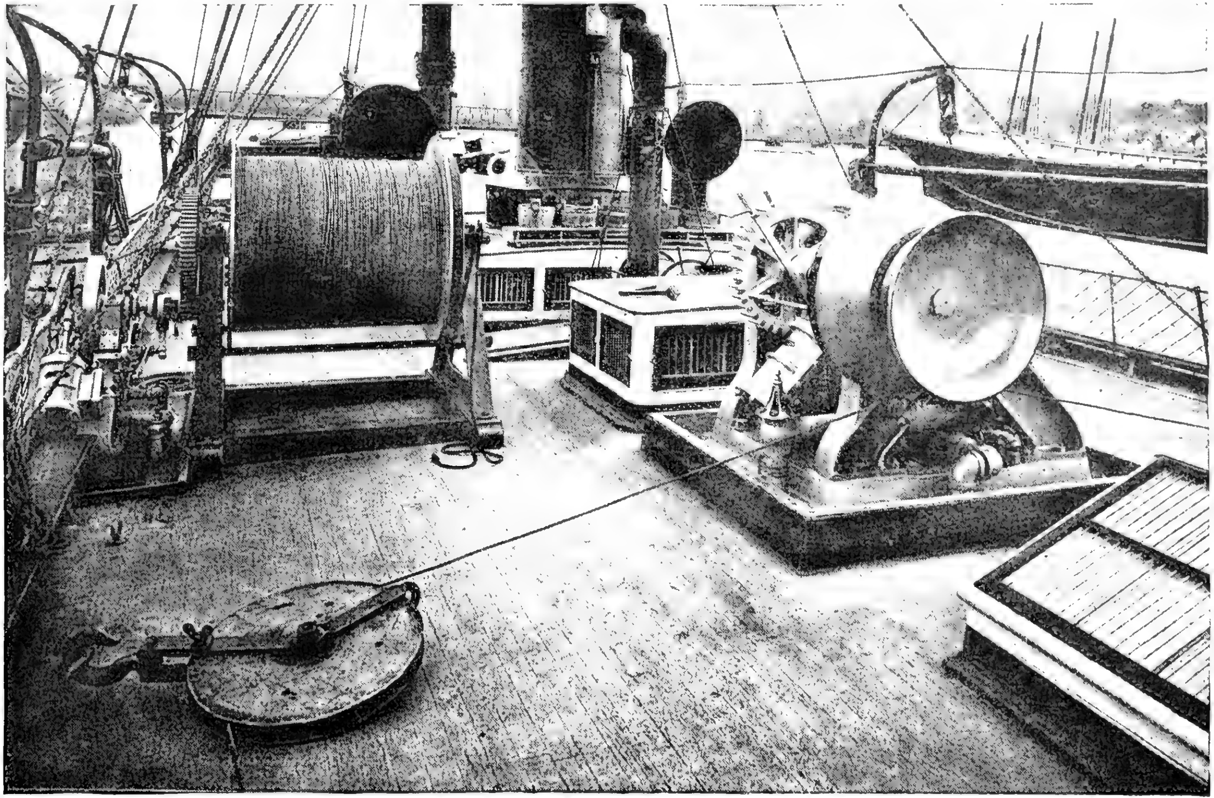


Fig. 29*a*. — "BLAKE" DECK LOOKING AFT, READY FOR DREDGING, REELING ENGINE, DRUM, LEADING BLOCK. (Sigsbee.)

Between the reeling-engine and the drum the wire rope is led on deck through heavy iron sheaves, and is guided in the same way over the bow. The dredging-boom (Fig. 29) moves on a swivel, and can be raised or swung sideways to facilitate the bringing of the trawl on deck after a haul has been completed.

The small size of the "Blake"[1] (one hundred and forty feet on the water line, twenty-six feet and six inches beam, with a draught of only eleven feet) rendered many devices necessary for the easy handling of the wire rope. As it was not considered best to bring the strain of hoisting directly upon the winding-reel, and as considerable room was required to handle the slack of the wire rope as it passed from the surging-drum to the reel, we sent the rope by means of blocks round the deck almost back again to the surging-drum. (Figs. 29 *a*, 30.) The close proximity of the reel and drum enabled the men at the brakes to watch either engine readily and act accordingly.

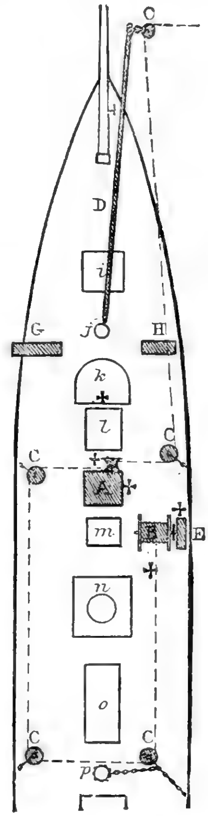


Fig. 30. — Plan of Deck of "Blake." (Sigsbee.)

B. Dredging-reel for wire rope.
C. Snatch-blocks.
A. Hoisting-engine.
D. Swinging-boom.
K. Pilot-house.
G. Sounding-machine.
H. Reeling-engine.

The plan of the flush upper deck of the "Blake" (Fig. 30) gives the position of the large iron reel *B*, on which the steel-wire dredging-rope was coiled, the position of the snatch-blocks *C*, leading the rope to the winding-engine with surging-drum *A*, to *C*, and then to the large block *C*, at the end of the swinging dredging-boom *D*, — this last block, *C*, being connected with the accumulator hung along the foremast; the position of the sounding-machine, *G*, on the port side is also shown, and that of the small winding-engine to reel in the sounding-wire.

In paying out the wire rope for a haul after the trawl or

[1] The "Blake" is schooner-rigged, her speed but moderate, and with a consumption of four tons, steams about eight knots. She can carry coal at that rate of consumption for thirty-eight days' steaming.

dredge was over the side, and everything ready for lowering, the reeling-engine was reversed slowly until the trawl was well started, when the lowering could be done somewhat more rapidly; and as soon as sufficient wire had been payed out, so that its weight and that of the trawl were great enough to overcome the resistance to the descent of the rope, then steam was shut off and the wire was managed entirely by the friction-brake. During the lowering, the steamer was very slowly backed, and as soon as the trawl was well planted she was backed more rapidly, until, according to the soundings, an additional amount of rope equal to from a third to twice the depth had been payed out. Then, when the wire rope was well fast, the steamer was backed at the rate of a mile and a half to three miles an hour, according to the nature of the bottom, dragging the trawl for a length of time varying from ten to twenty minutes. In hauling up, the winding-engine was again brought into requisition, great care being taken, when the trawl or dredge broke ground, that the movement should be slow at first when the strain of the trawl and its load came upon the wire rope.

A new crew requires a little practice to become familiar with the working of the machinery, and in our first attempt off Havana we came to grief by paying out the dredge-rope too fast. This produced a tangle of about two hundred fathoms of steel wire, the cause of which was easily explained when we saw the hopeless result; but it also taught us the speed at which we should lower and the proper manner of handling the vessel during the operation, so that the accident was altogether a most fortunate one for the future progress of the work.

Intimately connected with the fauna of great depths is the pelagic fauna. The innumerable marine animals which always live at or near the surface, either during their whole life or merely during their earlier stages of existence, play an important part in the economy of the deep-water fauna. The surface of the ocean on calm days swarms with pelagic mollusks, crustacea, echinoderms, jelly-fish, and the like, either adults or embryos, associated with foraminifera and sponges. The surface animals are collected by means of a hand-net (Fig. 31) made of

fine gauze, or of a net of similar material (Fig. 32), towed behind a boat moving quite slowly. At the least ripple of wind they retreat out of reach of the disturbance, and occupy a belt of water probably one hundred, or at the outside one hundred and fifty fathoms in depth. When they die their shells or hard parts slowly find their way to the bottom, to serve, before they are completely decomposed, as food for the deep-water forms. The shells of many foraminifera and the like being found apparently in such a fresh state at the bottom, it was supposed that many of these pelagic forms only came up accidentally, and really lived at or near the bottom. This seemed the more probable because there are undoubtedly many types of foraminifera which are inhabitants of deep water. Still, the investigations of Müller, Pourtalès, Schultze, Haeckel, and of all the naturalists accustomed to the study of pelagic forms plainly showed that a great number of the types of which the dead remains were found on the bottom really passed their existence as pelagic forms near the surface, within a comparatively narrow belt, where they could find the greatest abundance of food.

Fig. 31. — Scoop-Net.

The naturalists of the "Challenger" attempted to prove during her cruise that some of these forms lived at great depths, and that there was practically no belt of ocean entirely barren

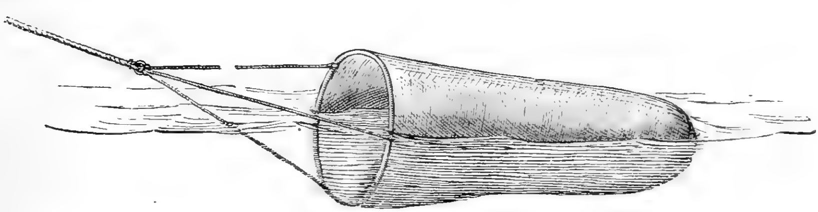


Fig. 32. — Tow-Net.

of animal life. The means adopted on the "Challenger" to solve the problem did not, however, settle the point definitely. The old practice was employed of dragging for animal forms at intermediate depths by means of a tow-net, which, during the

several operations of lowering, dragging, and hauling back remained open; this cannot be regarded as affording acceptable evidence of the habitat of such specimens as were obtained. It became an interesting problem on the "Blake" to determine accurately how far these pelagic forms really extend. Lieutenant-Commander Sigsbee contrived a machine intended to furnish means for solving this problem.[1] It consisted of a copper cylinder to be sent down closed on a collecting expedition to any depth desired, when it was opened by a messenger; being

[1] Sigsbee's apparatus consists of a cylinder, covered with gauze at the upper end, and having a flap-valve at the lower end. The cylinder is heavy enough to acquire a rapid vertical descent between any two depths, — the valve during the descent keeps open, but remains closed during the processes of lowering and hauling back with the rope. An idea of what it is intended to effect may thus be stated briefly: specimens are to be obtained between the intermediate depths a and b, the former being the uppermost. With the apparatus in position, there is at a the cylinder suspended from a friction-clamp in such a way that the weight of the cylinder and its frame keeps the valve closed; at b there is a friction-buffer. Everything being ready, a small weight or messenger is sent down, which on striking the clamp disengages the latter and also the cylinder, when messenger, clamp, and cylinder descend by their own weight to b, with the valve open during the passage. When the cylinder-frame strikes the buffer at b, the valve is thereupon closed, and it is kept closed thereafter by the weight of the messenger, clamp, and cylinder. The friction-buffer, which is four inches long, may be regulated on board to give as many feet of cushioning as desired. The accompanying sketch of the trap (Fig. 33) explains itself. The copper cylinder A is retained in place by screw-bolts. It is riveted to a wrought-iron frame B, has a flap-valve C, fastened to a long lever D, pivoting at E. The top of the cylinder is covered by a wire sieve, and in addition there is a wire-gauze funnel or trap H, inside the cylinder. The cylinder is hung to the friction-clamp K, by an excentric tumbler P, which is released whenever the messenger X strikes it, allowing the messenger, cylinder, and clamp to travel with the valve open till it strikes at the requisite depth the buffer Q. The valve is then closed, the cylinder drawn up, and the contents of the sieves carefully examined on deck.

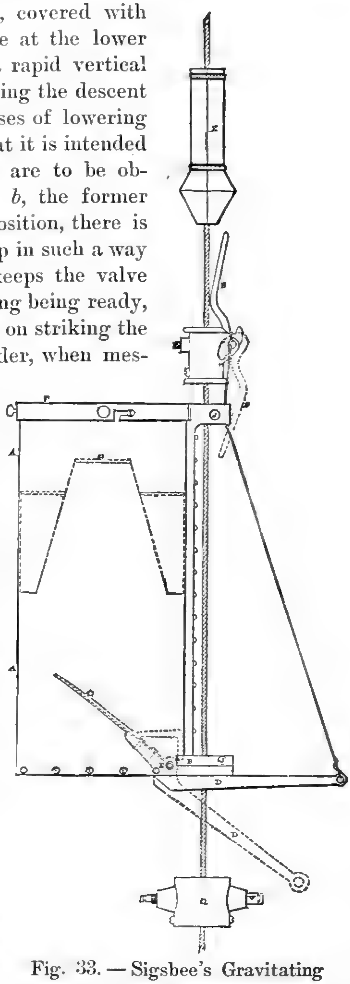


Fig. 33. — Sigsbee's Gravitating Trap. (Sigsbee.)

opened, it was allowed to run on say from five to fifty fathoms on the wire rope, and on reaching the lower point it closed again. The cylinder was then brought up with great care and the contents examined. In a similar way it was sent to collect the pelagic forms between fifty and one hundred fathoms in depth, and finally those of the intermediate belt between one hundred and one hundred and fifty fathoms. As was anticipated, the cylinder contained in the first experiment — from five to fifty fathoms — about the same pelagic forms as were found on the surface at the locality where the cylinder was sent down. In the second experiment, — from fifty to one hundred fathoms, — the same forms were found again, though greatly diminished in number, and the water of the third trial was found to be entirely barren of animal life. This collecting-cylinder was tried once off the eastern extremity of George's Bank, and a second time in the axis of the Gulf Stream, in localities where the surface fauna was very abundant, and could be followed with the eye down to a moderate depth. These experiments serve to prove that the pelagic fauna does not extend to considerable depths, and that there is at sea an immense intermediate belt in which no living animals are found, nothing but the dead bodies which are on their way to the bottom. The collecting-cylinder should also be modified so as to drag at intermediate depths horizontally. Whenever this is done, the question can be definitely settled.[1]

The "Blake" has now been on three dredging cruises, and has been employed every winter since 1874 in deep-sea soundings. During the first dredging season in the Gulf of Mexico in the winter of 1877–78, the "Blake" was commanded by Lieutenant-Commander C. D. Sigsbee. To his inventive genius is due the efficient equipment of the "Blake," and his suggestions have greatly modified all the apparatus originally in use on the vessel.

The officers spared neither pains nor work to accomplish the

[1] It is stated in "Nature" of August 4, 1884, that a tow-net which opens and closes automatically, invented by Captain Palumbo of the Italian corvette "Vettor Pisani," is invariably sent down with the thermometer-wire, and that it has worked successfully.

best possible results. Their interest in the work never flagged, and they have now attained a proficiency in deep-sea work hardly deemed possible ten years ago. By the old methods a single dredging at depths of from twelve hundred to eighteen hundred fathoms occupied nearly twenty-four hours. It was not an uncommon occurrence for the "Blake" to make six, or even seven hauls a day in depths varying from seven hundred to eighteen hundred fathoms. The deepest sounding made by the "Blake" was in 3,428 fathoms; the deepest haul of the trawl in 2,412 fathoms.

During the second cruise among the West India Islands and the third cruise along the eastern coast of the United States, the "Blake" was commanded by Commander J. R. Bartlett, whose interest in the work was not less than that of his predecessor in command. It is pleasant to notice that the harmony between the naturalists and the officers of the "Blake" was not for an instant disturbed during the time they were working in common. Everything in the way of naval routine was sacrificed for the time to the objects of the cruise, and the appearance of the deck and bow of the "Blake" was often more that of a mud-scow than of a vessel in the service of the United States.

II.

HISTORICAL SKETCH OF DEEP-SEA WORK.

Our knowledge of the depths of the sea was only incidentally increased by the work of the great French, English, and Russian exploring expeditions, sent on voyages of circumnavigation. They collected interesting isolated facts regarding the distribution of temperature, the density of the sea-water, and the existence of animal life at great depths. Boyle and Hooke in the seventeenth century both speculated and experimented as to the saltness of the sea; Ellis, in the middle of the eighteenth century, observed the temperature of the water from a depth of nearly 900 fathoms. This observation, like many of the early deep-sea temperature observations, was made by bringing up the sea-water in a closed vessel and observing the temperature when it was brought on deck. To Sir Joseph Hooker, when naturalist of the Ross Antarctic expedition, we owe the interesting observation regarding the occurrence of surface desmids in the bottom specimens of the dredgings of Sir James Ross. It was principally from observations made in the Arctic and Antarctic exploring expeditions that our first accurate knowledge was obtained of the distribution of the temperature of the deep sea, of the nature of the bottom, and of animal life at very great depths. The observations of temperature, however, were not sufficiently accurate for the requirements of modern physics, the thermometers used not being protected from the great pressure to which they frequently were exposed.

Within the last twenty years the investigations of the depths of the sea have taken an immense development. Previous to 1866 several important exploring expeditions had made it a part of their programme to sound at great depths and examine, as far as was possible with the instruments then in use, the physical

conditions of the strata of water below the surface. But no expedition had been fitted out for that purpose alone. In fact, the opinion was current among naturalists that beyond the 300 fathom line the field of the zoölogist was a barren one, notwithstanding the many facts to the contrary which had been accumulating [1] little by little since the beginning of the century. The true bearing and full importance of these discoveries were appreciated only by a few naturalists, who attempted in vain to counterbalance the authority of Edward Forbes, the most brilliant naturalist perhaps of his time.

The deep-sea work of Forbes in the Ægean Sea (1841) led to the general acceptance of his theory that animal life was limited to a comparatively shallow depth (300 fathoms). The peculiar physical condition of the region studied by Forbes may perhaps account for the results he obtained. For a time they overshadowed later contradictory facts, as when in 1861, for instance, living creatures were brought up by a telegraph cable from a depth of over 2,000 fathoms in the Mediterranean. Yet in spite of this, the poor success which attended the cruises of the "Porcupine" and "Shearwater" in the Mediterranean led Dr. Carpenter to assume that in that sea, below a few hundred fathoms, life became practically extinct. It was reserved for the French exploring expedition of the "Travailleur" and of the "Talisman," [2] in charge of Alphonse Milne-Edwards, to show that while the great depths of the Mediterranean are not so full of animal life as the corresponding depths of the Atlantic, they yet contain favorable localities in which many of the Atlantic deep-sea species may be found and were actually collected by the French expedition. The great depths of the Mediterranean are mainly covered by a thick bed of gray mud little favorable to the development of animal life; and this fact, taken in connection with the comparatively high temperature of that sea at the bottom, would fully account for the paucity of animal life.

[1] Umbellula was brought up off the coast of Greenland by Adrians in the middle of the last century from a depth of 1,406 feet in 70° N. L., and the specimens were described by Ellis. In 1871 the same species was found again and described by Lindahl from specimens collected by the "Ingegerd" and "Gladan."

[2] The cruise of the "Talisman" to the westward of the Atlantic coast of Africa, 1882, led to some most important results.

These results were abundantly confirmed subsequently by the rich collections made by Professor Giglioli in the "Washington" (Captain Magnaghi), sent out by the Italian Government to explore the depths of the Mediterranean. While the deep-water species of the Mediterranean are, without exception, also found in the abyssal region of the Atlantic, it is also true that the Mediterranean contains only such deep-water species as can bear a somewhat high temperature. We may consider that all enclosed seas like the Sulu Sea, or inland seas like the Mediterranean, the Red Sea, the Caribbean, and Gulf of Mexico, have received their fauna from the adjoining oceans. When from some cause or other the colder water of the great depths was shut out from a free circulation, only such species as were capable of living in a comparatively high temperature survived. The fact that in the Mediterranean we find fossil Arctic forms, such as occur in the glacial deposits of England and Sweden, and are still found in the Italian pliocene deposits, shows plainly that the temperature of the Mediterranean must have been different in former geological times from what it is now.

While naturalists were discussing the absence of animal life below three hundred fathoms, Portuguese fishermen were taking deep-sea sharks from nearly five hundred fathoms, and bringing up occasionally a glass sponge (Holtenia) on their lines. Japanese fishermen had also been catching a very similar shark in three hundred fathoms, often drawing up with it a Hyalonema which found its way to Europe as a great curiosity of Japanese art. No attention was paid to the existence of the many animals which from the end of the last century were shown to live at great depths. Indeed, the occurrence of animal life in the deeper waters of the ocean seemed to produce no impression on scientific men, although in deep water on the two sides of the northern part of the Atlantic, a number of species of fishes, which could only subsist on animal life, were constantly caught, thus plainly proving the existence of a varied animal fauna at those depths. No attention was paid to the early observations of Sir John Ross (1818) in Baffin's Bay where, at the depth of between 800 and 1,000 fathoms, a fine Astrophyton was brought up on the sounding line. The extensive collections made by

Torell at depths of over 1,000 fathoms, during his first expedition to Spitzbergen, were only noticed by Keferstein [1] in 1846. Similar observations by Sir James Clark Ross (1841) in the Antarctic Ocean, at a depth of 400 fathoms, passed equally without notice.

Yet as early as 1863 Professor Lovén [2] at the Meeting of Scandinavian Naturalists held in Stockholm, gave a Report on the expeditions of Torell to Greenland and Spitzbergen, in 1859 and 1861. These had demonstrated beyond doubt (with the dredge) the existence at the deepest point reached (250 to 300 fathoms) of a fauna belonging to all the classes of marine invertebrates. With the "Bulldog" machine Torell brought up from the great depth of 1,000 and 1,400 fathoms foraminifera, mollusca, annelids, crustacea, echinoderms, and sponges. In 1868 Sars [3] published a long list of animals dredged to a depth of 450 fathoms by his son G. O. Sars, off the coast of Norway, since 1862. These belonged to all groups of marine invertebrates and seemed to show without doubt, as was well put by Lovén, that off the Norwegian coast, at least, the zero point of animal life had not yet been discovered; he further threw out hints in regard to the existence of a uniform abyssal fauna over the bottom of the Oceans which have formed the basis of all subsequent speculations on this subject. From that time the Swedes and Norwegians have been most zealous in their explorations of the physics and natural history of the Arctic regions. They have sent expeditions to Iceland, to Spitzbergen, and Greenland, with Smitt, Goës, Ljungman, and Malmgren as zoölogists, and although dredging had not then been developed to its full extent, a few hauls were made by the "Bulldog" machine to a depth of 2,600 fathoms, which showed the existence at those depths of a large number of invertebrates. Their last expeditions were those of Nordenskiöld and of the "Josephine" (which ran a section across the Atlantic) with Captain Von Otter as Commander. He had been the successful chief of the earlier expedition of the "Sofia" to the Arctic region.

[1] Nachricht. d. K. Gesell. d. Wiss. z. Göttingen, 1846.

[2] See also Rept. Brit. Ass. Adv. Sc. York Meeting, 1844.

[3] In 1850 Sars gave a preliminary account of a dredging trip to the Lofoten Islands in 1849.

In Great Britain, ever since the time of Forbes, dredging expeditions have been undertaken, limited, however, to the more shallow regions accessible by private means. The reports of the dredging committee of the British Association have made the names of Gwyn Jeffreys, of Norman, of Barrett, and Andrews, familiar to students of marine zoölogy, while in this country the shore dredgings of Stimpson, Dr. Ayres, Lieutenant Kurtz, and of expeditions sent out by the Cambridge Museum form the beginning of American investigations.

The successful deep dredgings of the Norwegian, Swedish, and American expeditions were followed by the English expeditions with which the name of Wyville Thomson will forever be associated.

Sir Wyville Thomson, who visited Norway to examine the collection of deep-sea animals made by the elder and younger Sars, from depths varying between 350 and 500 fathoms, could not fail to be struck with the variety of the fauna they had collected. The discovery of Rhizocrinus, a small stalked crinoid, the representative of a family of fossil sea-lilies, which had become extinct with the chalk, opened to him a vista of what might be accomplished by a systematic exploration of the great ocean abysses. He had the great satisfaction, in connection with Dr. Carpenter and Mr. Gwyn Jeffreys, to see in succession the "Lightning," "Porcupine," "Valorous," and "Shearwater" placed at their disposal. These explorations culminated in the "Challenger" expedition, one of the most remarkable scientific explorations sent out by any government.

In 1868, the "Lightning" with Thomson and Carpenter explored the regions between the Færöes and Scotland, and made successful hauls to a depth of 680 fathoms. The two following years the "Porcupine" was placed at the disposal of Messrs. Carpenter, Jeffreys, and Thomson, and more extended explorations were made off the coast of Ireland, the Bay of Biscay, in the Atlantic, off Spain, and in the Mediterranean. The ship was provided with the improved Miller-Casella thermometer for taking the temperatures. These expeditions may be said to have awakened in European naturalists general interest in the importance of such investigations, and to have settled once for

all the question of the existence of animal life at the bottom of the sea at all depths, — a varied fauna having been discovered by the many casts in deep water at which the expedition dredged, the greatest depth being 2,400 fathoms, then considered an enormous one for the dredges.

But the crowning work of the English in this direction was the "Challenger" expedition. A man-of-war of 2,300 tons was dispatched in 1873, commanded by Sir George Nares, with Sir Wyville Thomson as scientific chief. The "Challenger"[1] was gone three and a half years. She sailed or steamed over 69,000 miles, and crossed and recrossed the great oceanic basins, dredging and sounding, and making physical observations at no less than 360 stations. Indeed, the work of the "Challenger" extended over the whole globe. Previous investigations had been undertaken on a more limited scale along the coast of North America, and in the North Atlantic and Arctic regions, by the Norwegian,[2] Swedish, Danish, American, and English nations.

Any account of the work of the English would be incomplete without a mention of the important results, published in 1862, obtained by Dr. Wallich on the "Bulldog" in 1860. These results, however, received from naturalists but little attention. Dr. Wallich advocated the view that the condition of the bottom of the sea was favorable to the existence of animal life at the greatest depths; unfortunately, the animals collected by him, as well as by Sir James C. Ross, belonged to groups which might live (and do, as we now know) at the surface, or to the starfishes, which we could suppose might have floated out far from the sea-shore, and finally have sunk. An Astrophyton can swim to a certain extent, and starfishes can float for a long time on the surface of the water, with their suckers uppermost. Had, however, naturalists paid sufficient attention to the Reports of Alph. Milne-Edwards, and Professor Fleeming Jenkin, concerning the animals found growing attached to the cable laid at a depth of 2,000 fathoms between Sardinia and Africa, the

[1] Additional deep-sea work was also undertaken by the "Triton" and "Knight Errant" (Murray and Tizard).

[2] Vöringen expeditions, 1876 - 1878 (Mohn, Danielssen, and G. O. Sars).

arguments of Dr. Wallich would not have waited so many years for the recognition to which they were so justly entitled, and the bearing of which the French naturalist fully perceived.

Of the more important of the early publications which have little by little called attention to the presence of animal life at great depths, we may mention, in addition to those of the Rosses, the later (1853) papers of Professor Bailey of West Point, who examined the soundings submitted to him in 1850 by Professor Bache, the superintendent of the United States Coast Survey. Professor Bailey was among the first to perceive the great importance of the results for biology and geology. These soundings extended to a depth of nearly 2,000 fathoms, and we find here the first discussion of the mode of existence of the foraminifera. Professor Bailey considered that they did not live on the bottom; he further compared the nature of a part of the Atlantic ooze to the chalk of England, and that of another to our green sand. Bailey's views were not supported by Ehrenberg, who argued that the foraminifera lived on the bottom where they were dredged. A very guarded report on the same subject was written by Huxley on the soundings of Captain Dayman of the "Cyclops" in 1857 (from a depth of 2,400 fathoms). He inclined to the opinion that the foraminifera lived at the bottom, and called attention also, as Bailey had done, to the great extension of globigerinæ, and to the existence of genera dating back even earlier than to the time of the chalk.

Maffitt and Craven investigated (1852) Gulf Stream globigerinæ: chalk formed of globigerinæ. Ehrenberg began in 1850 his researches on the living and fossil marine organisms of great depths. Then came the important memoir of Wallich, the naturalist of the "Bulldog," commanded by Sir Leopold McClintock (1860). He confirmed the results of Bailey and Huxley in regard to globigerinæ, and described ophiurans, crustaceans, serpulæ, from a depth of 465 fathoms. Then follow the explorations of Pourtalès, from 1867 to 1869, in connection with the United States Coast Survey, in the "Corwin" and "Bibb."[1]

[1] Bull. M. C. Z., No. 6, Dec. 1867, and No. 7, Dec. 1868.

As early as in Cook's second voyage, Foster attempted to obtain the temperature of the ocean below the surface. As one of the results obtained by Krusenstern's circumnavigating voyage, it was supposed that the temperature of the oceans at great depths was uniform. But all the earlier observations were defective from inaccurate soundings, and from the absence of attempt to correct the temperature observations for pressure. Among these we may mention those of the Arctic expeditions of the Rosses, the Scoresbys, the Parrys, Franklin, and others. As early as 1773, in Phipps's Arctic expedition, temperature observations were taken at considerable depths.

Lenz, on Kotzebue's second voyage, corrected his observations for pressure, and obtained a temperature of 3.05° C. at a depth of about 960 fathoms. He was the first to establish the fact that at the equator the cold water (bathymetrical isotherms) was much nearer the surface than in the more temperate zones either to the north or south of it. Yet, until a comparatively recent time the idea was prevalent that below a certain depth the ocean preserved a uniform temperature of 4° C., although we possessed the very definite observations taken by the United States Coast Survey officers, which annually recorded lower temperatures, taken with instruments improved for each year's work. It was not until the Miller-Casella thermometer came into general use, after being employed by the "Lightning" and "Porcupine," that extensive thermometric observations were made sufficiently accurate to serve as the foundation of oceanic temperature sections. We now have the broad outlines of ocean temperatures, thanks mainly to the observations made under the direction of the United States Coast Survey, and by the "Lightning," "Porcupine,"[1] the "Tuscarora," the "Challenger," and the "Gazelle," with a number of other vessels of the Swedish, Danish, Italian, Norwegian, English, French, and American navies.

[1] Pouillet and Humboldt seem both to have been struck with the importance of some of the early observations on deep-sea temperature, and Pouillet distinctly states that the phenomena of ocean temperatures could be best explained by the hypothesis of an interchange of water between the poles and equatorial regions, depending on a difference of temperature ; but this seems to have made no impression on geographers.

The earlier deep-sea soundings were made with the usual lines and leads, only somewhat heavier of course; as the depths increased, the difficulty of ascertaining when bottom had been reached became greater and greater. Attempts were made to sound with wire as early as 1849, by Lieutenant Walsh, U. S. N., and Captain Barnet, R. N., neither of which were successful. An earlier attempt to sound with copper wire, also unsuccessful, was made in 1842 by the United States exploring expedition under Wilkes.

In 1850 Captain Platt of the U. S. schooner "Albany," with cod-line and a heavy sinker, applied the method of determining the depth by time-intervals as first suggested by Rear Admiral W. R. Rogers. In doing this the line sent out was left behind and the amount of twine lost was considerable, small vessels going out fitted up with 40,000 fathoms of line. In 1854 Passed-Midshipman Brooke invented his detacher, so that the line could be hauled in again, and Commander Sands perfected in 1857 a cup which could bring back specimens of the bottom. In 1868 the Hydra machine was invented; it was in general use by the English navy for deep-sea work till comparatively lately. In 1872 Sir William Thomson invented his machine for sounding with wire, and a new era for accurate deep-sea work commenced.

Commander Belknap devised a number of improvements in this machine, and thus modified, it was in constant use during the first season of the "Blake's" work. To Belknap belongs the credit, not only of having first demonstrated the possibility of using Sir William Thomson's machine for taking accurate soundings in great depths, but also of having made the deepest soundings yet taken (off the coast of Japan in 4,655 fathoms.[1] The result has taught us that there are in the ocean, generally not very far from the shore lines, immense depressions of the sea-bottom, which, in their relations to the topography

[1] The accuracy of the deepest sounding made by Commander Belknap has repeatedly been questioned by naval authorities, because the wire broke while reeling in. Any one experienced in deep-sea sounding with wire must know that the depth is accurately recorded on deck the moment the wire stops running out, and that it is not necessary to bring up a specimen of the bottom to make an accurate sounding. Lieutenant-Commander Brownson brought up a bottom specimen from a depth only 94 fathoms less than that obtained by Commander Belknap.

of the ocean beds, can only be compared to the highest peaks in the Andes and in the Himalaya chain. Similar gigantic precipices or depressions have been subsequently discovered by the "Challenger," and by Commander Bartlett of the "Blake," in the Western Caribbean, and by Lieutenant-Commander Brownson, off Porto Rico (4,561 fathoms).

Although replaced in part by the trawl which was first used in very deep water by the "Challenger," the dredge has played a most important part in all except the latest explorations. It dates back to O. F. Müller (1779); it was used by Forbes as modified by Ball in 1838, and with slight modifications by all the more recent expeditions. It was, however, little in use on the great expeditions before 1860, though in 1801, Péron is said to have made casts with it. The Wilkes exploring expedition in 1841 also used the dredge. Dr. Stimpson (1853) seems to have been the first naturalist to handle it systematically within moderate depths in oceanic basins, during the North Pacific exploring expedition under Ringgold and Rodgers.

Now, however, the United States Fish Commission use the trawl almost exclusively in deep water. The same practice was also observed on the "Blake" expedition, and on the "Talisman." The United States Fish Commission and the French deep-sea expeditions have adopted for dredging the steel-wire rope first introduced for that purpose on board the "Blake," and it was found greatly to accelerate the trawling operations.

The publications of the "Depths of the Sea," of the "Voyage of the Challenger," by Sir Wyville Thomson, of the "Narrative" since his death, of "Notes" of the expedition, by Professor Moseley, and of "Thalassa," by Dr. Wild, have made the public familiar with the work of the English in the exploration of the depths of the ocean. But little is known even in America of the important part taken by the United States Coast Survey in the solution of the problems of the physical geography of the sea, or Thalassography.

The Coast Survey, during the superintendence of Professor Bache, instituted a series of investigations (begun as early as 1846) on the physical problems of the deep-sea, connected with the Gulf Stream, which, little by little, were expanded by his

successors, Professor Benjamin Peirce, Carlile P. Patterson, and Julius E. Hilgard, into the most important hydrographic coast exploration yet undertaken by any government. With a wise liberality, secondary hydrographic scientific problems, mainly of interest to the biologist and geologist, have been connected with the work of the United States Coast Survey, while sections were carried on across the Gulf Stream under the direction of Lieutenant Craven in 1855, and subsequently under that of Lieutenants Maffitt, Murray, Sands, Bache, Davis, and others. In 1850 the extended biological survey of the Florida reefs by Professor L. Agassiz was undertaken at the request of the U. S. Coast Survey. The beginning of a more systematic deep-sea exploration was made by Pourtalès and Mitchell, assistants of the U. S. Coast Survey, in 1867. During the explorations of Pourtalès of that year, and of 1868 in the "Corwin" and "Bibb," dredging operations were carried on between Florida and Cuba, and a depth of 850 fathoms was reached. The collections were most interesting, and the first publications of the results of the corals and echinoderms by L. F. Pourtalès and A. Agassiz showed as clearly as possible the antique character of the fauna then discovered, and the relationship which it indicated to the cretaceous period, rather than to the animals living upon the adjoining shores. An immense number of new types were also discovered, and it became very plain that the fauna living on the bottom along the course of the Gulf Stream was one of the most interesting known to science.

The character of the bottom samples also first showed to Agassiz that the deposits going on at the bottom of the ocean, at great depths, were very different from the shore deposits which as a general rule characterize all geological formations;[1] and that the modern chalk was not very different probably from the old chalk of the cretaceous period. The expedition of the United States Coast Survey steamer "Hassler," Commander Johnson (1871), which sailed with Professor L. Agassiz from Boston to San Francisco, did not fulfil the expectations of its projectors.

[1] Among the earlier publications relating to the nature of the off-shore bottom, see Delesse, Lithologie des Mers de France et des Mers principales du Globe. Paris, 1871.

A systematic exploration of the Gulf of Mexico was begun in 1872 by Commander Howell, U. S. N., on the West Coast of Florida, in comparatively shallow water, and was continued and brought to a successful conclusion by Lieutenant-Commander Sigsbee (1875–78) in the United States Coast Survey steamer "Blake." The deep-sea hydrographic work of the "Blake" was preceded by a number of soundings taken by the old methods, across the Straits of Florida, along the Florida Reefs, and across the Gulf Stream beyond the Straits of Bemini. Wire soundings were begun on the "Blake" in August, 1874, while she was in charge of Commander John A. Howell, U. S. N., the apparatus employed being Sir William Thomson's machine for sounding with piano-wire, as modified by Commander George E. Belknap, U. S. N.

The expeditions of Pourtalès were followed in 1877–80 by the dredging cruises of the "Blake," a vessel built especially for the hydrographic work of the Coast Survey, and thoroughly fitted out for deep-sea dredging and sounding-work in 1877. The "Blake" explorations extended through the Caribbean (Bartlett commanding), the Gulf of Mexico (Sigsbee commanding), the Straits of Florida, and the east coast of the United States as far north as George's Bank. To these expeditions I was attached in charge of the dredging operations. The deepest trawling of the "Blake" was in 2,423 fathoms, and the deepest sounding taken by the "Blake," in 1882, by Lieutenant-Commander Brownson, off Porto Rico, was in a depth of 4,561 fathoms. Finally, we must mention the extended operations of the United States Fish Commission, directed by Professor S. F. Baird, assisted by a large staff of specialists. These commenced in 1871 with naval tugs, and were carried on at first in moderate depths. With the building of the "Fish-Hawk" in 1882, the operations were extended into somewhat deeper waters off the east coast of the United States; the equipment of the "Albatross" in 1883 supplied the Fish Commission with the best equipped dredger for deep-sea work in existence; and the work of the Commission is now extended to the deepest water along the American coast.

After the close of the Civil War the Coast Survey resumed

its former activity; and since 1866, the use of the dredge, the trawl, the tangles, and all the apparatus necessary for a thorough exploration of the fauna of the depths of the sea, has become as familiar to some of the navy officers attached to the Coast Survey as the use of the sextant or the lead, and the Coast Survey steamers, "Bibb, "Hassler," and "Blake" have acquired a unique reputation as deep-sea dredgers. Not only naturalists, but also hydrographers must be interested in Sigsbee's volume on deep-sea work, published by the Coast Survey, with its detailed account of the equipment of the "Blake," — a small steamer of only three hundred and fifty tons burden, which, under the skilful command of Lieutenant-Commander Sigsbee and Commander Bartlett, has done not only more rapid, but also far more accurate work than has been accomplished with the old methods and appliances by the large men-of-war usually detailed for similar work by European governments. The work of the "Bibb" and "Hassler" is known to naturalists mainly from the memoirs of Pourtalès. Only a part of the results of the work done on the "Blake" under my direction has as yet been published in the Bulletins and Memoirs of the Museum of Comparative Zoölogy.

But we are only at the beginning of these investigations, and we have much to learn as yet of the physiology of the ocean. We have merely skimmed the surface thus far, and have only traced a few thin lines with the dredge and trawl over the bottom of the oceans.

The work of the Scandinavians has been supplemented by that of the Americans, and the general agreement of the results is most satisfactory. These results have, in their turn, been greatly extended by the English, and subsequently by the Americans. Italians and French again have added to the stock of common knowledge which formed the basis for the great "Challenger" expedition.

III.

THE FLORIDA REEFS.

Florida projects between the Gulf of Mexico and the Atlantic as a broad, low peninsula, not strictly limited to the land which rises above the level of the sea. Extensive shoals on its southern extremity reach between the mainland and the line of keys, and stretch nearly as far west as the Tortugas. Taken in connection with the immense bank to the westward of the peninsula, they form the continuation of the mainland, below the surface, to about the hundred-fathom line, — the mass of the Florida plateau proper. To this must be added the narrower coast-shelf of the eastern face of the peninsula. This shelf has, however, a very different character; for on the eastern side of the peninsula, the calcareous or coral sand gives way to the siliceous sand characteristic of the eastern Atlantic coast south of Cape Hatteras.

The shore line of the southern extremity of the peninsula is ill-defined, and, with the exception of the short stretch between Cape Sable and Cape Florida, marked by bluffs of coral limestone, is similar to that of the Everglades. It consists mainly of innumerable low islands separated by narrow channels from the mainland, to which it becomes united by flats, often bare at low water. Similar flats, but far more extensive, stretch westward from the mainland, back of the keys as far as to the northward of Key West and the Marquesas. (Fig. 34.)

Portions of these flats are dry at low tide, and are separated by occasional patches, more or less extensive, of deep water. The water which covers these flats gradually deepens as one passes westward from the mainland. The flats, as well as the whole of the tract of surface between the mainland and the Tortugas, dip slightly to the westward. These shoals are liter-

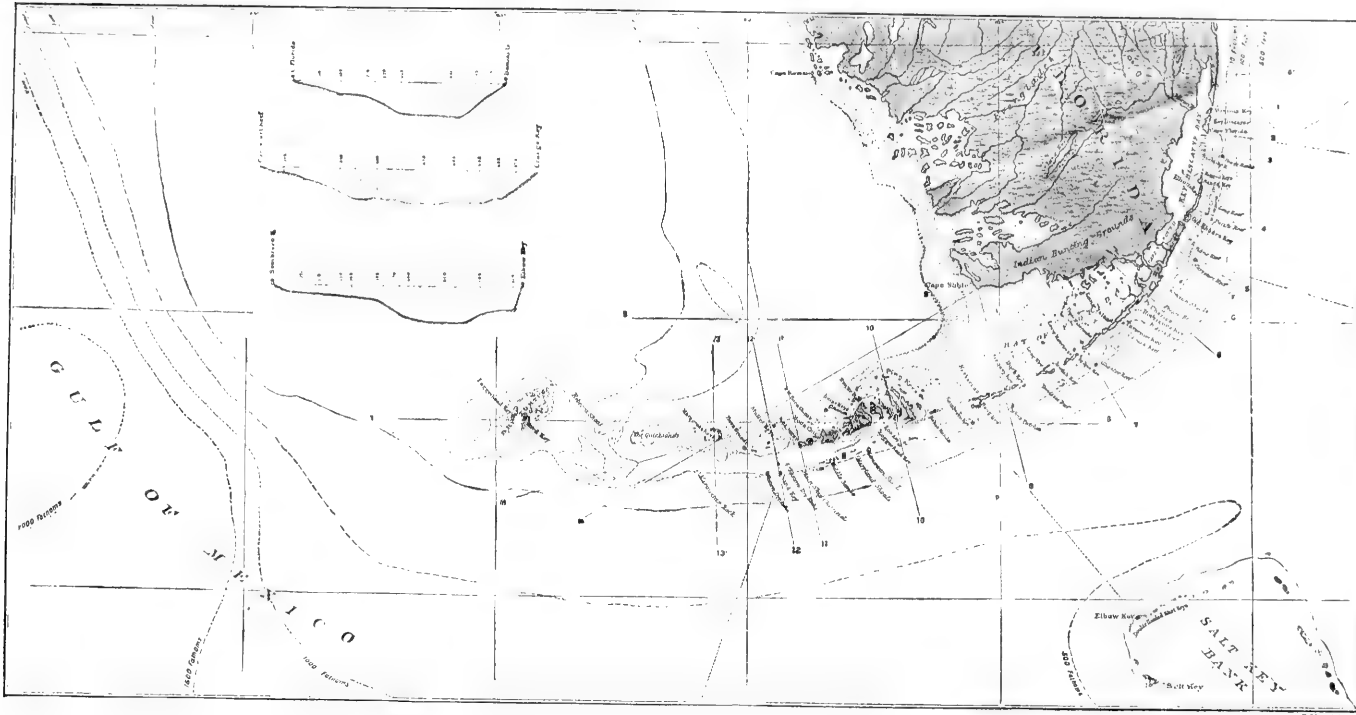


Fig. 34.—STRAITS OF FLORIDA, FROM COAST SURVEY CHARTS.

B Meisel, lith.

ally studded with mangrove islands, often arranged without any apparent regularity, either forming continuous ranges or small archipelagos, broken by narrow and shallow channels. The vegetation of these low islands is most luxuriant, and consists mainly of mangroves.

Upon the flats which have reached the surface of the sea the young mangrove plants drift in immense quantities. They are fusiform bodies of about six inches in length, resembling a cigar; they float vertically, and when once stranded soon work their way into the soft mud of the flats, and take root, sending out shoots in all directions. The new stem rises rapidly, sending down new shoots to the ground from higher points, forming thus an arch of roots from which spread the branches of the mangrove trees. Around such a nucleus additional sand and mud soon collect, and gradually build up extensive islands, covered with a thick tangle of mangroves and other plants. The mangrove islands on the flats to the north of Key West are specially noteworthy. (Fig. 35.) The keys proper are all similar in structure, and form an extensive chain of low islands, rising nowhere more than about twelve feet above the level of the sea. Starting from north of Cape Florida, they form an immense crescent extending as far west as the Tortugas. The keys usually consist of the accumulation of dead corals, or of coral rock or coral sand cemented into a greater or less degree of compactness. The principal ones are long, narrow islands, varying in width from a mile to less than a quarter of a mile, and in length from mere patches to such islands as Key Largo, Indian Key, or Key West, the longest of which extends about fifteen miles. The keys are separated by shallow channels; they all slope very gradually to the north into the mud flats, and present their steepest face to the south on the shores which skirt the ship channel that separates them from the reef proper.

The reef proper forms a curve similar to that of the keys, never receding from them more than from three to fifteen miles. The channel thus formed, which separates the reef from the keys, is navigable for small vessels the whole length of the reef as far as Cape Florida. The reef reaches the surface of the sea at only a few points, as at Carysfort, Alligator Reef, and Ten-

nessee Reef. At other points it forms extensive shoals, which are covered with a few feet of water. In other localities again, the pounding of the breakers on the edges of the reefs has accumulated dead corals which form small keys along the line of the main reef, as at Sand Key, Sombrero, and the Samboes. There are passages of greater or less depth across several parts of the reef, giving access from the Gulf Stream to the interior ship channel. The main entrances to Key West Harbor are formed by such channels. The depth of water on the reef, like that of the mud flats, increases as one passes from Cape Florida towards Sand Key and the Marquesas.

The small keys of the reef proper are built of accumulations of larger coral boulders forming the foundation pieces of corals, and fragments of shell and coral sand arranged according to their size in the interstices, and heaped up by the action of the waves, the tides, and the winds. Similar agencies must have formed the keys proper, for they consist of the same coral rock and sand, acted upon for a much greater length of time by the storms.

A walk along the sea-face of any one of the keys will show its coast line to be in incessant movement. In exposed places

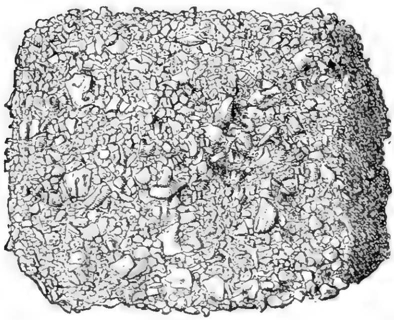


Fig. 36. — Coral Breccia.

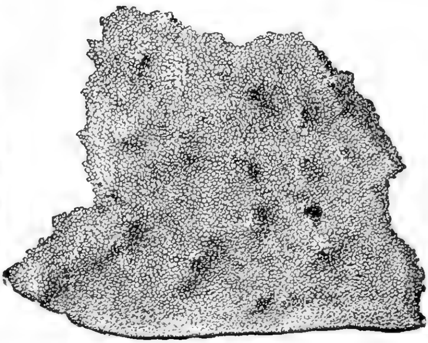


Fig. 37. — Coral Oölite.

the larger fragments broken off by the breakers from the coral rock of the shores are split into smaller fragments, which in their turn are changed to pebbles, and then finally become cemented into coarser or finer sand or impalpable powder. The cementation of these fragments at different stages gives us the

Fig. 35. — DISTANT MANGROVE ISLANDS SEEN FROM MANGROVE BEACH NORTH OF SLAUGHTER HOUSE, KEY WEST.

so-called coral breccia (Fig. 36), and the different grades of oölitic (Fig. 37) or compact limestone characteristic of the recent reef formation.

The coral boulders are the remnants of huge masses of astreans and mæandrinas, and similar species of corals. The broken fragments of corals come from the different species of branching madrepores and porites or the smaller masses, such as Manicina, Agaricia, and the like; while the fragments of shells, etc., are derived from the limestone carcasses of the hosts of invertebrates which once lived on the active coral reef. The boring mollusks, annelids, and sponges have little by little riddled masses of corals with their burrows, weakening them to such an extent that the breakers pounding upon the exposed sea-faces of the reef break off larger or smaller masses; these are then heaped up and ground together to form either the top of the reef proper or the inner keys, as just described.

Of course it can hardly be expected that, with all this pounding and grinding and constant rehandling of the material which goes to make the limestone rock of the keys, many animal remains should be preserved intact. In fact, with the exception of fragments of the stouter shells of some of the mollusks or tubes of annelids and the like, there are but few organic remains to be found.

Corallines, or limestone algæ, also play a most important part in the formation of keys. They grow in great abundance upon flats and upon the dead fields of corals which have reached the surface of the sea; their joints are easily recognized in the components of the coral sand of many a Florida key. Nowhere else along the reef or the line of the keys do we find indications that the highest elevation of the land is due to any causes except those now acting in the formation of the keys. There is not a single point so high that it cannot be reached by the waves in severe storms, or the elevation of which cannot be traced to the action of the tides and winds upon the material of the shore lines.

All naturalists who have visited the Florida reefs have felt the difficulty of applying Darwin's theory of reef formation to the peculiar conditions existing along the Straits of Florida. Agassiz, Le Conte, and E. B. Hunt have each in succession attempted

to explain, from a different standpoint, the mode of formation of the Florida reefs. Agassiz stated, and his statement was afterward confirmed by Le Conte, that the Florida reefs had a distinctive character, and could not be explained by subsidence, to which cause Darwin had ascribed the formation of barrier reefs in general. In his report[1] on this subject, Agassiz has shown, not only that the southern extremity of Florida is of comparatively recent growth, but that the causes by which it has for the greater part been built up are still going on, and that we have a specimen, as it were, of the past action in the mode of growth of the present reef, keys, and mud flats. He shows that the whole southern portion of Florida is built of concentric barrier reefs, which have been gradually cemented into a continuous sheet of land by the accumulation and consolidation of mud flats between them, — a process which is now going on between the Florida keys and reefs from Cape Florida to the Tortugas, and must end in transforming them, in like manner, into a continuous tract, to be connected eventually with the mainland.

In Agassiz's report no attempt is made to explain the substructure of the peninsula upon which the reef-corals grow. Le Conte, however, attributed this substratum to the mass of material brought along by the Gulf Stream. He believed that the Gulf Stream once ran parallel with the line of the present peninsula, and that the substratum was formed by the heaping up of these loose materials along that line. All the later investigations show, however, that the Gulf Stream never followed this course. Then, as now, it swept across, and not parallel with, the line of the peninsula, and though it undoubtedly assisted in the building up of Florida, it simply brought then, as it does to-day, the food, or the greater part of the food, consumed by the animals living on the Bank of Florida. These animals supply, by their growth and decay, the building material for the great Florida Bank. No doubt, the floating animals brought by the Gulf Stream add something besides to the mass of the bank itself; but they are chiefly consumed by the animals living upon it.

[1] Mem. Mus. Comp. Zoöl. VII. No. I. 1880.

The curve of the Florida Reef (Fig. 34) along the Gulf Stream is due in great measure, as Hunt shows, to a counter current along the reef, running westward. This current is known to all navigators, and though ill-defined at Cape Florida, becomes stronger and wider as it goes west. It has a width of at least ten miles at Key West, and of twenty miles at the Tortugas. This is clearly shown by the mass of surface animals driven along upon this westerly counter current by the south-easterly winds.

The tides set strongly across the reefs, and through the channels between the keys, the flood running north and the ebb south. When storms occur, the fine silt of the bank, made up of coral sand from the reefs, is taken into the bay back of the keys and deposited there. The counter current then carries this to the westward, and thus material has gradually been added to the flats. As Hunt has already noticed, tides and currents have undoubtedly been the principal agents here. That this material has not been brought by the Gulf Stream from the mouth of the Mississippi, is shown by the fact that no trace of Mississippi mud has ever been found in any of the innumerable soundings taken to the eastward of the Mississippi, or more than a hundred miles from its mouth. It is also probable that the action of the waves from the southeast, in forming a talus of coarser material, does not penetrate below one hundred fathoms, and everything once fixed below that depth has its final character. The line of keys seems to be formed by the waste of the exterior present reef, rather than by the remains of an older anterior reef. At the Tortugas, the contrary seems to be the case; but this perhaps is due to the fact that the strong currents which sweep over the reefs, and have excavated the Southwest Channel, have also established conditions favorable to the growth of corals on both sides of this channel, and that the two lines of keys are due to this cause. Had the currents run only from the southeast through the Northwest Passage, larger keys, separated by channels running north and south, would then have been formed.

I shall first show by an examination of the Tortugas[1] how

[1] A. Agassiz, The Florida Reefs; Mem. Am. Acad. xi. 1883.

far the explanations given by Agassiz, Le Conte, and Hunt are satisfactory as regards the formation of the group of islands making the extremity of the reef, and shall then attempt, by the help of the dredging operations of the "Blake" along the Florida Bank, to reconstruct the past history of the peninsula in its southern portion. Beginning with an account of the formation of the present reef, based upon the knowledge obtained by a careful survey of the Tortugas, I shall then proceed to the elucidation of the structure of the peninsula itself.

The Tortugas (Fig. 38) are situated at the very extremity of

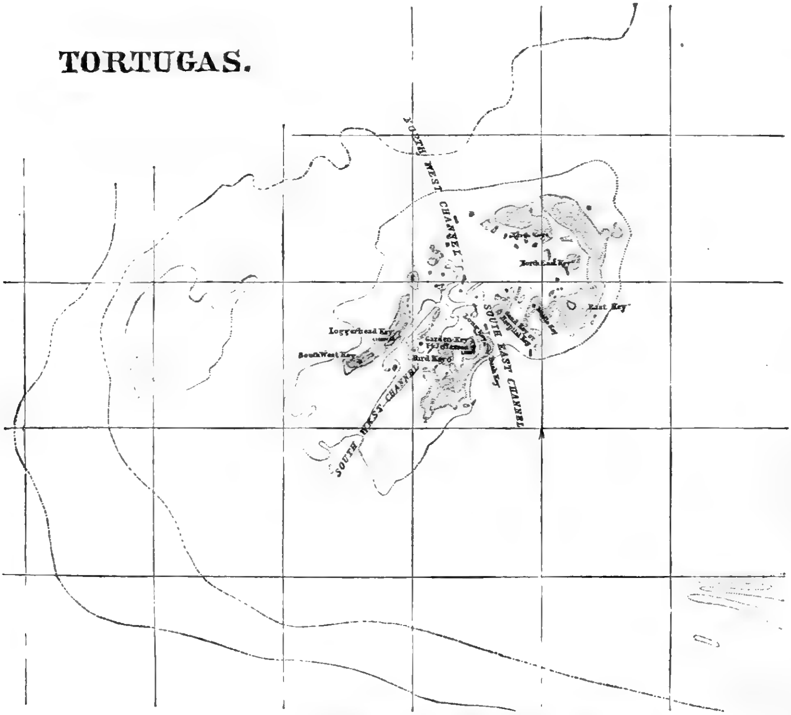


Fig. 38. — The Tortugas from Coast Survey Charts.

the slope upon which the line of the Florida reefs has been built up. They form the most recent of the cluster of Florida reefs, and have not as yet been transformed into the normal coral reef characteristic of the whole line extending from the Rebecca Shoal and Marquesas to Cape Florida. There is as yet nothing at the Tortugas corresponding to the extensive mud flat stretch-

ing uninterruptedly, a few feet below the surface of the water, to the northward of the line of keys. (Fig. 34.) The northern part of this flat, from Cape Sable to Key Biscayne, is fringed on the southeast face by the line of narrow keys reaching from Cape Florida to Bahia Honda. (Fig. 34.) In the oldest part of the reef, the bay to the north of the keys, the waters of which once undoubtedly covered the whole space between Pine Keys and Cape Sable, has little by little been filled up and transformed for the greater part into the wide, shallow mud flats now extending over that area. Next comes, from the Pine Keys to Rebecca Shoal, a comparatively more recent portion of the reef, in which the northern extremities of the keys rise somewhat higher above the general level of the mud flats.

These two adjoining regions of flats and keys run parallel to the main reef, at a distance of from one to nine miles from the outer line of reefs, — the reef, that is, *par excellence*, over the whole surface of which the living corals still prosper. Farther yet to the westward, at a distance of fifteen miles from the western extremity of the outer parts of the reef, rise the Tortugas. In this group a condition of things prevails at the present day which must have been repeated over and over again, from the time when the Florida Reef formed but an insignificant point south of the line extending from Cape Sable to Key Biscayne, until it reached the extremity of the present continuous mud flat, about ten miles to the west of the Marquesas. As is well shown on the Coast Survey maps, the mud flats, keys, and reef, dip as a whole to the southwest, as does also the Florida plateau which extends to the westward of the Marquesas. It is only upon such parts of this plateau as from some cause or other have attained a sufficient elevation to allow corals to flourish that the reef may be expected to extend. Such an area is the knoll rising above the general level upon which the Tortugas have little by little been built up; and such also is the patch to the westward of the Tortugas, upon which, as I shall show hereafter, an incipient coral reef is already forming, at a depth of a little less than twenty fathoms. (Fig. 38.)

It is not difficult to go back to a time when the great mud flats of Florida did not exist. In their place was a steep slope,

such as we now find to the west of the Tortugas. Continuing the parallel, it is easy to imagine how, little by little, since easterly winds and currents prevailed, materials coming from the small outside reefs and held in suspension were gradually driven to the westward, and accumulated finally upon what was then the extremity of the great Florida Bank. There they gave rise to knolls similar to those upon which the Tortugas have been built. From the moment these knolls attained a sufficiently favorable elevation for the growth of corals, a western reef was formed, holding to the small Florida Reef then existing very much the same relations as the Tortugas at the present day hold to the great Florida Reef. Again, by the same agencies, the channels which once undoubtedly ran back into the mud flats to the north of the oldest keys were gradually closed, since such channels as are still open, in part or wholly, in the more recent and westerly portions of the reef, as, for instance, the entrance to Key West Harbor, run from the south to the north across from the reef to the mud flats. In like manner these channels, and those which form an extensive strait in the most recent part of the reef between Rebecca Shoal and the Tortugas, will in time disappear, and become, in consequence of the extension of the mud flats beyond Rebecca Shoal, narrow channels, like those of Key West, of the Pine Keys, and of the Marquesas. By this time there will also have been formed an extension of the outer reefs along the twenty-fathom line, connecting the Tortugas with the present reef, and only broken here and there by passages similar to those already existing along the reef, by which vessels find free access to the middle passage between the reef and keys. These channels are kept open by the same tidal agencies as are now more powerfully at work at the Tortugas, but which have gradually diminished in force from the Pine Key Channel to the northward. The depth of the passage between the Tortugas and Rebecca Shoal allows a larger and stronger body of water to pass through that channel than through any other.

It has been clearly proved by Hunt that the extensive flats to the northward of the keys have been formed by the agency of the tides, the whole triangular space between the Rebecca Shoal

and Cape Sable being filled up with silt. Since the flood runs in a northerly and the ebb in a southerly direction, the tides in their alternation hold in suspension the silt which they wear away from the reef or from the shores of the keys. During storms this floating silt is driven either on to the flats to the north of the keys, or on to the slope of the reef toward the Gulf Stream. An examination of the present condition of the Tortugas, and of the mud flats beyond the Marquesas, gives us a very simple explanation of the formation, and gradual extension westward to its present limits, of the small reef originally existing only as a diminutive spit, but gradually spreading to the southwest from Cape Florida until it has reached its present gigantic proportions.

The Tortugas show us, as will be seen, how the reef was actually formed, while the extension of the mud flats beyond the Marquesas explains how the bottom is prepared and gradually raised to a level at which corals will flourish. One other condition was, however, essential to the development of the coral reef, — that of the existence of a powerful current, such as the Gulf Stream, bringing an immense quantity of pelagic animals to serve as food for the corals found along its path. There is practically no evidence that the Florida Reef, or any part of the southern peninsula of Florida which has been formed by corals, owes its existence to the effect of elevation; or that the atolls of this district, such as those of the Marquesas or of the great Alacran Reef, owe their peculiar structure to subsidence.

It cannot be denied that the backbone of the Florida peninsula was first produced by a fold of the earth crust in an earlier geological period. Smith and Hilgard have also shown that such a fold or folds formed the axis which has raised a part of the northern base of the peninsula to a height of something less than two hundred feet; and that this axis, which has still, at the latitude of Lake Okeechobee, an elevation of about forty feet, but sinks gradually as we go south, was formed before the Vicksburg limestone age, while on either side of it are deposited the more recent limestones which have given Florida its present width. They have pointed out, moreover, as a secondary result

of this folding, the formation of an immense submarine plateau, directly in the track of the Gulf Stream, by the accretions of the solid parts of mollusks, echinoderms, corals, halcyonoids, annelids, crustacea, and the like, which have lived and died upon it; these solid parts have furnished the limestone for the gradual completion of the peninsula. No one who has not dredged near the hundred-fathom line on the west coast of the great Florida plateau can form any idea of the amount of animal life which can be sustained upon a small area under suitable conditions of existence. It was no uncommon thing for us to bring up in the trawl or dredge large fragments of the modern limestone now in process of formation, consisting of the dead carcasses of the very species now living on the top of this recent limestone. To the westward of the western shore line, Florida now stretches out as an immense submarine plateau, forming, as the sections show, a huge tongue coated or veneered only by coral limestone over its very top. The whole of the peninsula of Florida south of St. Augustine, as far as Tampa Bay, has probably in this way been built up from north to south, of limestone somewhat older than the reef limestone. The plateau, judging from the inclination of the axis, has but a slight southward dip until one reaches the southern extremity of the peninsula, where the fall is more rapid toward the outer reef.

The whole of the eastern and western edges of Florida consist of recent limestones, the immediate predecessors of that which is now forming on the western and southern slopes of the great Florida plateau. The early dredgings of Mr. Pourtalès, in 1867 and 1868, developed on the Gulf Stream slope off the Florida reefs an extensive rocky plateau (Pourtalès Plateau) from a depth of about ninety fathoms to about two hundred and fifty fathoms. The rock of which this plateau is built (see Fig. 192) consists of the same species of corals and shells as those now living upon it, to which it owes its formation.[1] A similar sea-bottom is found on the north side of Cuba,

[1] Mr. S. P. Sharples, who examined specimens of rock from the Pourtalès Plateau, found the corals made up of about ninety-five per cent. of carbonate of lime, the balance being organic matter and phosphate of lime.

The recent limestone found on the Pourtalès Plateau contained from thirty-

but with a much steeper slope. These fringing limestones also formed the southern extremity of Florida at a time when the northern part of the Everglades had perhaps been built up to a level favorable for the growth of coral reefs.

In the northern portion of the Everglades alone can we confidently speak of the first concentric reefs, which have little by little built up Florida toward the south. It seems highly probable that on the remainder of the peninsula north of the Everglades, both the newer and older limestones were built up by the same agencies now at work on the Florida Bank. There are to-day other submarine banks which undoubtedly owe their origin to similar agencies. The great bank to the east of the Mosquito coast, which practically extends to Jamaica, has probably been formed in the same way as the Yucatan and Florida banks; that is, by the gradual decay of the animals subsisting in great abundance upon its slope, and fed by the pelagic materials which the currents and the prevailing winds bring to the bank, and which have been pouring upon the top of the plateau for ages past. All the reefs on the south coast of Cuba between the Isle of Pines and the shore of the east and west may have had a similar origin. Among the West India Islands the barrier reefs of the windward side are built upon plateaux of a similar structure. The Grande Terre of Guadeloupe is a fine example of such a plateau, which has been elevated slightly above the level of the sea. At Barbados the whole shell of the island consists of a series of terraces, which have been successively lifted by the trachytic centre that forms the nucleus of the island. These terraces are entirely composed of limestone formed of the species of mollusks and radiates now living in the West India seas.

six to forty-seven per cent. of carbonate of lime and from thirty to thirty-five per cent. of phosphate of lime, with ten to twelve per cent. of carbonate of magnesia, and from ten to twelve per cent. of oxide of iron. This large amount of iron is probably brought down by the rivers, and, coming in contact with the decomposing organic matter, is deposited as a carbonate, and then slowly changed to a sesquioxide.

The most recent limestone contains, like the corals of which it is almost entirely made up, ninety-six per cent. of carbonate of lime and a little silica. In the ooze the amount of carbonate of lime was eighty-five per cent., there being also over four per cent. of carbonate of magnesia, and eight per cent. of organic matter, with about one and one half per cent. of silica, and only a trace of phosphoric acid, which distinguishes this ooze from Atlantic ooze.

While there is thus undoubted evidence that a great part of the shore line of the northeast extremity of South America has been washed away, there is also evidence that the lines of the bank connecting the lesser West India Islands have been built up by agencies similar to those which have formed the Yucatan and Florida banks, except that these latter have been formed around the volcanic islands or folds which extend along the eastern edge of the Caribbean Sea. In some cases these banks have been elevated since the existing condition of things came about; in others their elevation dates back to the period when the separation of the Caribbean from the Pacific took place, at the time of the closing of the Isthmus of Panama. Evidence of this action is found in the elevated coral reefs and the raised earlier tertiary and later cretaceous deposits of the West Indies and Central America.

Nowhere do we find better examples than in the West India Islands of the formation of submarine banks in connection with volcanic peaks. A great number of peaks of volcanic origin have risen nearly to the surface of the sea, or above it, and serve as the foundation of great submarine or littoral banks. It is well known, also, that the "Challenger" and "Tuscarora" soundings have developed a number of submarine elevations, covered by deposits of pteropod and globigerina ooze, and these deposits form extensive banks which serve as foundations for barrier reefs and atolls, while the volcanic substratum has been completely hidden. In the West Indies, as at Martinique, there are volcanic peaks rising to a height of over four thousand feet; on their windward side are extensive submarine plateaux, formed, I imagine, by agencies similar to those to which we ascribe the formation of the Yucatan and Florida plateaux. Whenever such plateaux have reached on their windward side the level at which corals prosper, there coral reefs spring up and flourish. Side by side with such conditions we find plateaux at lower levels, under a greater depth of water, covered only by the invertebrates living upon their surface, — as is the case, for instance, in the northern extremity of the plateau of the Grenadines. These plateaux have probably never risen to the surface. We have also the still older phenomenon of such

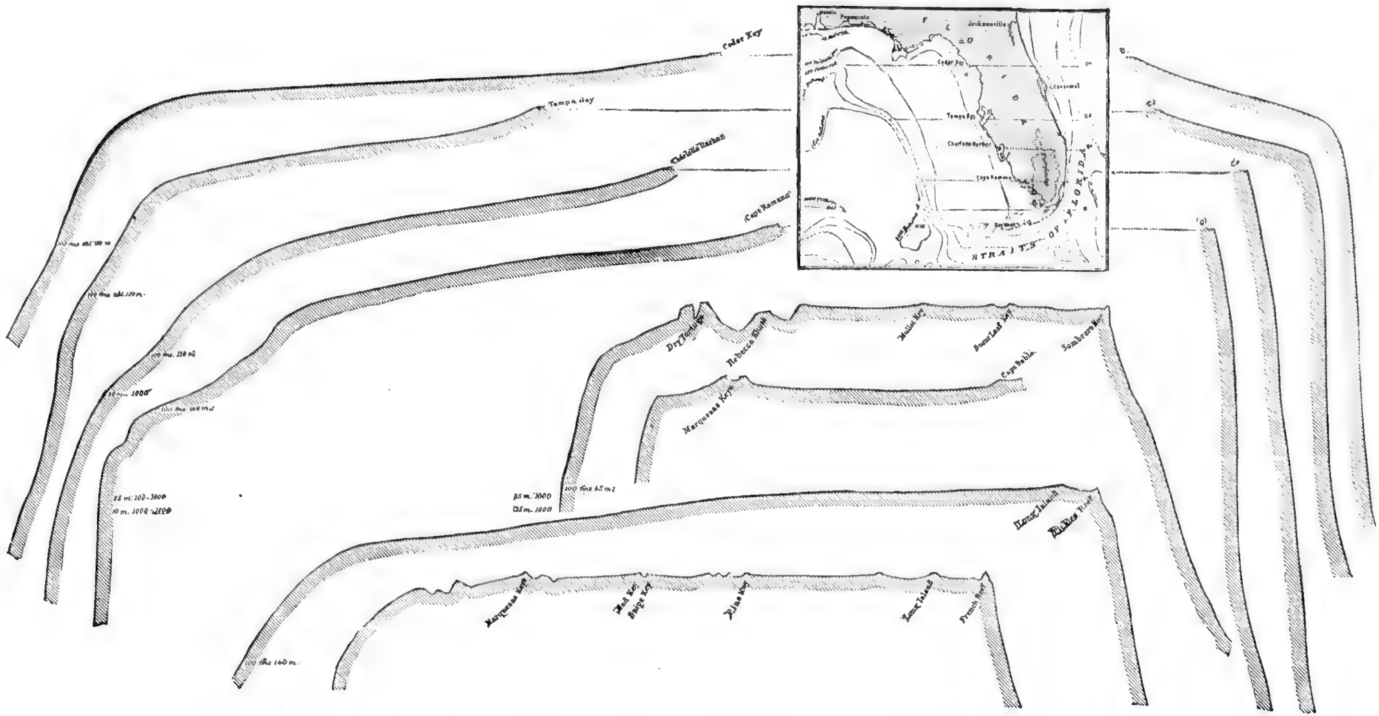


FIG. 40. — SECTIONS ACROSS THE PENINSULA OF FLORIDA.

islands as Barbados (Fig. 39), where the terraces formed by the raised coral reefs mark the successive elevation of the volcanic cone; or we may have still another combination, like that of Guadeloupe, where a high volcanic peak forms the main island, and an elevated plateau forms the Grande Terre with a growing coral reef to the windward.

The fact that these great submarine banks of modern limestone lie in the very track of the great oceanic currents sufficiently shows that these currents hold the immense quantity of carbonate of lime needed in the growth of the bank. Its amount has, besides, been actually measured by Murray. He

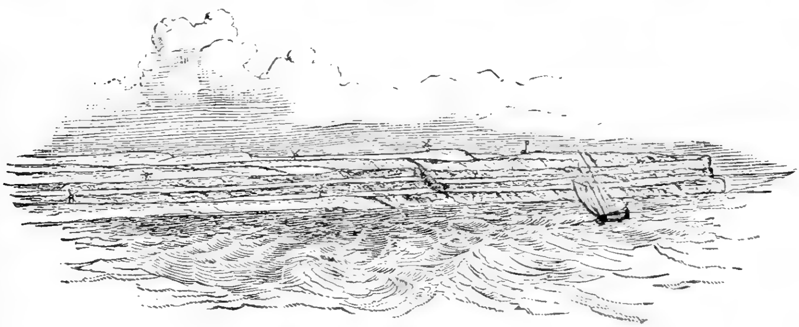


Fig. 39. — Barbados Terraces.

has shown that, if the pelagic fauna and flora extend, as the experiments carried on by the "Challenger" and the "Blake" seem conclusively to prove, to a depth of one hundred fathoms, we should have sixteen tons of carbonate of lime for every square mile one hundred fathoms deep. But the greater the depth at which these plateaux begin to form, the less rapid must be their formation. The fact that the deeper part of the ocean, below three thousand fathoms, does not contain any of the larger shells of pelagic type can be readily explained on the supposition that these, being very thin, like pteropod shells, present a large surface to the action of the carbonic acid, which is most abundant in deep water. Attacked as soon as they reach deep water by this action, these shells of thinnest surface are reduced to a bicarbonate, and are carried off in solution. They do not, therefore, appear at these greater depths, and are

indeed rarely to be found below two thousand fathoms. The thicker-shelled foraminifera reach a greater depth, not because they are of different chemical composition, but because their greater amount of substance yields less easily to the solvent action of the acid or sea-water. At shallower depths the solvent action of carbonic acid must be far less efficient, since there is a rapid accumulation of dead siliceous and calcareous shells of foraminifera, sponges, hydroids, corals, halcyonoids, mollusks, polyzoa, echinoderms, etc., which must have lived upon the bank long before they had by their accumulation brought it to a level at which coral reefs could begin to grow.

The bathymetrical sections (Figs. 40, 41) of the peninsula of Florida to the eastward into the trough of the Gulf Stream are very different from those taken on the western side of the peninsula. Proceeding northward from Cape Florida, we pass out of the action of the current from the Straits of Bemini, where the velocity of the Gulf Stream is the greatest. As soon as we reach a latitude at which the trade winds do not blow, we come gradually upon the usual comparatively gentle slope off shore, which shows little trace of disturbance either from currents or from the action of the prevailing winds. Judging from what I have seen of the east coast of the peninsula of Florida, the shore line deposits, such as the coquina of St. Augustine and the shelly beaches of Indian River, indicate the presence in deep water of a limestone deposit formed of the detritus of mollusks, annelids, starfishes, and sea-urchins. There are a few corals only, and occasional patches of reef-builders, but no extensive reefs; but this is a difficult point to decide even at Key West. Indeed, all along the line of the reefs it would be hard to determine to-day whether the reefs have been formed, like the Marquesas Keys, merely by the accumulation of detrital matter driven to the westward and northward, or whether the Mangrove Keys and the reefs really indicate the old lines of a reef similar to the one now in full activity on the northern edge of the Gulf Stream, parallel to the main line of keys. The absence of the more delicate shells from limestone, in the formation of which they must nevertheless have shared, may be explained by the solvent action of carbonic acid upon them, and by the deposition

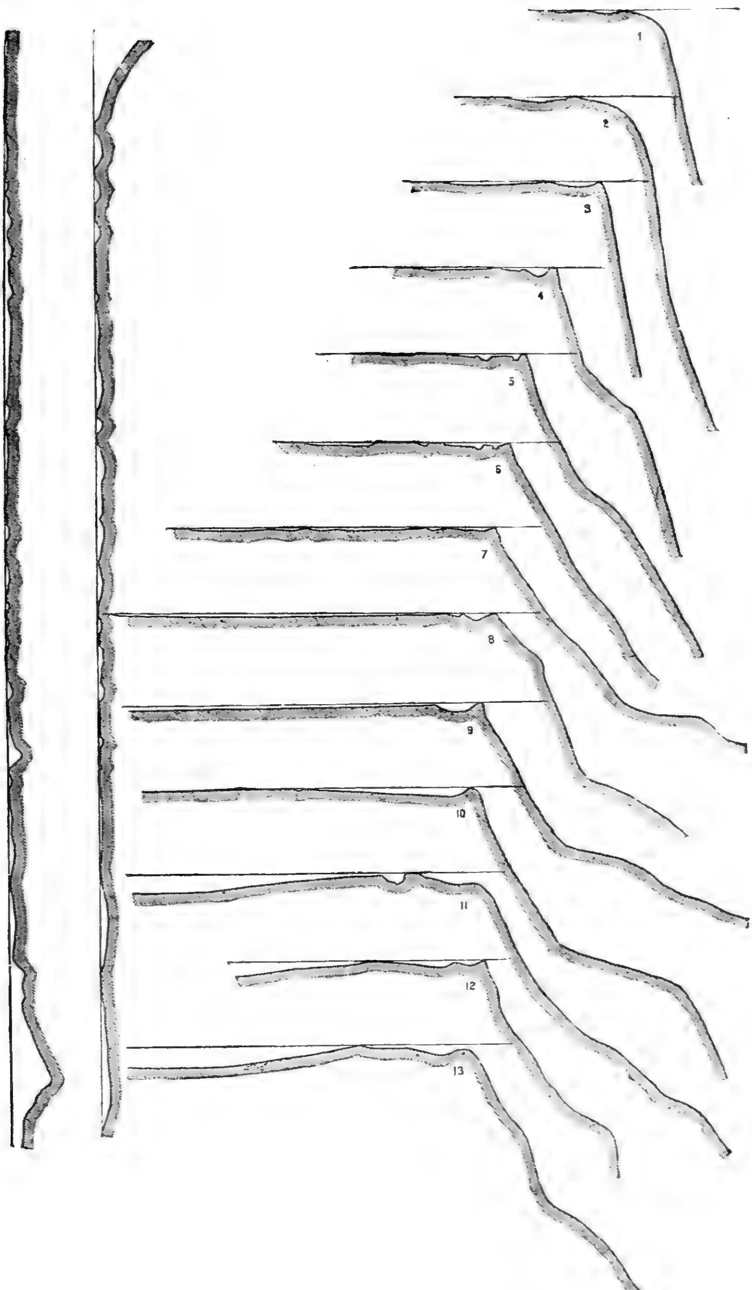


Fig. 41.—SECTIONS ACROSS THE FLORIDA REEF. See Fig. 34.

of carbonate of lime as a cement. A comparison of the structure of Loggerhead Key at the Tortugas with that of the Mangrove Islands and the main keys shows us the difficulty of deciding these points. At Loggerhead Key we have a shore line made up of brecciated and oölitic coral limestone, fully as characteristic as any similar shore line on the older keys like Key West (Fig. 42.) Yet we still find on the southern, eastern, and northern sides of Loggerhead an active growth of reef-building coral, while other parts of the island and some of the flats, if covered by mangroves, cannot be distinguished by their structure from the genuine mangrove islands on the flats to the north of the inner line of keys along the main reef. (Fig. 43.)

We must be careful to distinguish the line of islands running from the mouth of the St. John's to Cape Florida, and parallel with the coast of Florida, from the line of islands forming the Florida Keys. The latter seem at first glance to be the continuation of the former; but this is not the case, their mode of formation, as well as their geological structure, being radically different. As was long since pointed out by H. D. Rogers, the line of narrow islands to the eastward of Florida belongs to the series of coast islands lying parallel to the coast from Long Island to Florida, and extending around the whole Gulf of Mexico. They all seem to have been formed by the same cause; the action of currents along the continental shores has formed lines of deposit of but little width, and separated from the mainland by a shallow channel. Some of these islands have been slightly elevated at a comparatively recent period. This is especially the case with the islands along the east coast of Florida, Anastasia Island, and those running south to Cape Florida, separating Indian River from the Atlantic Ocean. In all these we find the so-called coquina of St. Augustine raised from ten to twenty feet above the level of the sea at such points as Anastasia, Merritt's, and Worth Islands, showing all along the east shore of Florida a very recent formation of shell *débris* or breccia, very similar to the formation now going on in the lagoons near Venice. This bed of shell breccia was probably deposited after the low backbone of the peninsula, extending perhaps from

southern Georgia and Alabama to the northern part of Lake Okeechobee and the Everglades, had been raised, and when the peninsula of Florida from the St. John's to the eastward was below the level of the sea at a shallow depth. At any rate, it seems plain from recent evidence that no trace of reef-building corals exists on the east coast north of Cape Florida. Mr. Dietz is inclined to look upon the formation of these islands as due to the action of the waves. But there seems to be nowhere, as is well stated by Rogers, any deposit of the kind going on now; and when such masses of shells are thrown up on beaches, the tendency is strong to consolidate from fragments to the concrete form known as coquina.[1] The mode of formation does not, however, seem adequately accounted for by the action of currents moving along the coasts. These currents must have flowed over a wide plateau, and have supplied the large amount of food needed for the development of a thriving bank of mollusks and other invertebrates. As soon as these growing colonies had risen high enough to form banks parallel to the shores, they were in their turn cut off and isolated from the shore by the action of the tides and currents, which must then have begun to deepen the channels intervening between the bars and the mainland. They must also have forced their way across the banks to form the shifting inlets, such as Mosquito Inlet, etc., so characteristic of the channels leading into the inland waters along our whole Southern Atlantic coast. The dip of the coquina bed to the westward is well shown by the borings of artesian wells at Palatka. I was informed by the contractor that he met the coquina beds at a depth of about forty feet, when he reached a mass of clay, which in its turn was underlaid by pebbles resembling the small pebbles found on flats off a rocky shore. Possibly this mass of clay was formed by the silt of the Gulf Stream at a time when it flowed over the low ridge of central Florida, before that ridge had risen to form a dividing line between the two plateaux, one of which must have extended to the westward much as at present, while the other undoubtedly extended in some localities north of Cape Cañaveral somewhat to the eastward of the present shore line of Florida.

[1] Fourth Report British Association, for 1834–1838, p. 11.

Fig. 42.—CORAL ROCK BEACH, NORTH OF FORT TAYLOR, EXPOSED TO ACTION OF WAVES OF CHANNEL BETWEEN OUTER REEF AND KEY WEST.

All this evidence tends to show that the coral reefs had little, if anything, to do with the building up of the peninsula of Florida north of Cape Florida. The existing line of reef is indeed probably the only one which has played any important part in the formation of land south of the line of the present southern extremity of the peninsula of Florida. There seems, however, some reason to believe that a line of reefs, or perhaps two lines not very distant from each other, once stretched along the southeastern end of the Everglades before the present reef began to extend westward. Judging from the sections shown by the maps, the growth of the present reef, as fast as the mud flats were formed to the south of it, has been altogether in that direction. (Figs. 40, 41.)

The Bahamas, the San Pedro, and Yucatan banks have probably all been formed by a similar process, — by the accumulation of limestone either upon an early fold of the earth's crust, or upon a volcanic plateau, or upon a foundation of slower growth from great depths. In Yucatan we can actually descend into the bank itself through any one of the aguadas, or caverns, found everywhere in the northern part of that country. Many of these caverns extend to a considerable depth; one of them, that of Bolonchen, has a depth of seventy fathoms, the whole formation consisting of recent limestone entirely composed of species of invertebrates now living on the Yucatan Bank. In Yucatan, as in Florida, we find a low ridge of limestone, somewhat older than that of the coast, extending across the peninsula. The uplifting of this ridge has caused the slight undulations of the surface traceable throughout Yucatan, at a distance of from twenty to thirty miles from the coast, and running nearly at right angles to it. Judging from its fossils and lithological characters, the limestone of which this ridge is formed is identical with the so-called Vicksburg limestone of the central backbone of Florida. The fauna of the Yucatan Bank is identical with that of the Florida Bank, being characterized by the same species of echinoderms, mollusks, crustaceans, corals, and fishes, so well known already from shallow water on the Florida side.

While on the Yucatan Bank I had the opportunity of exam-

ining the great Alacran Reef,[1] an excellent plan (Fig. 44) of which is given on one of the British Hydrographic maps of the Gulf of Mexico, from the surveys of Commander Barrett, R. N. It is one of the circular reefs resembling atolls, and I was the more desirous to get an idea of its mode of formation because, according to Darwin's theory of coral reefs, such atolls should not occur in areas of elevation like those in which the Florida reefs, the coast reefs of Cuba, the Bahamas, and the Central American reefs are found.

The examination of Alacran Reef showed it to be in full activity. The greatest length of the reef is about fourteen miles; its width, eight miles. It consists of a steep semicircular wall rising abruptly on the eastern side, which is also that of the prevailing winds, from a depth of thirty fathoms to ten fathoms, where the corals begin to grow, and the slope becomes much more gradual. The eastern edge of the reef presents a singularly regular section, where the huge masses of heads of *Madrepora palmata* form a nearly compact level wall, with its top flush with the level of the sea. This wall is constantly beaten by the sea, and the breakers, pounding upon the coral heads exposed to their action, detach large pieces or break off the dead masses, which are again triturated into smaller fragments until they form a fine sand swept by the wind in a westerly direction; this sand little by little fills up the channels left between the masses of coral which form the outer wall and extend towards the centre of the reef. The detritus from the outer reef diminishes gradually in quantity, and leaves a channel varying from three to nine fathoms in depth on the eastern edge of the low islands to which the reef dwindles at its western extremity. This channel describes deep indentations in the western edge of that section of the plateau which extends from the eastern edge of the reef. On the eastern edge of the islands the reef is completely choked with sand, while on the gentle western sea-slope of their outer side the corals are thriving, but creep out very gradually seaward instead of building a steep, abrupt wall like that of the outer edge of the reef.

It is probable that, in the case of an atoll of this sort formed

[1] Letter No. 1, Bull. M. C. Z., V. No. 1, April, 1878.

Fig. 43.—Lagoon formed by promontories and low islands covered with mangroves, northeast shore of Key West Island.

on a flat plateau, the low islands now constituting the western edge of the reef were at one time exposed to the full action of the sea. As their sea-slope became little by little surrounded by the wall now encircling the outer edge of the reef, the growth of the corals was checked, the interstices and spaces between the coral masses were gradually choked by sand and coral fragments, until the low islands now known as Perez, Chica Pajaros, and the great sand-bars of the western edge of the reef were slowly built up a few feet above the level of the sea, — mere strips of sand gradually cemented together by the accumulation of the loose materials held in suspension by the water.

The outer eastern edge of the reef or wall is from one to two hundred yards in width, and inside of this extends for a maximum distance of seven to eight miles an extensive section which is more or less filled with masses of astreans, of mæandrinas, of gorgonians, and madrepores in more or less irregular patches, with a general westerly trend. They reach nearly to the water's edge, where it is quiet, and are separated by deep gullies of clear water varying from one to seven fathoms in depth. Through these gullies a regular current sets to the westward, and has deposited on its path the coral sand held in suspension, thus keeping these gullies clear of coral and gorgonian growth. These heads are gradually but steadily approaching the western strip of islands, and will in time completely fill the whole space in the interior of the reef, or will leave only a narrow channel of various depth between the outer broad bank to the east and the narrow islands to the west.

The whole structure of this reef shows its identity of formation with that of the main Florida Reef, and with that of the reefs on the northern coast of Cuba, where the line of distinct and powerful elevation can still be plainly traced by old coral slopes and by the ancient coral reefs in the hills surrounding Havana and extending to Matanzas. These hills attain a height of over 1,200 feet, and are entirely composed of species of corals identical with those now found on the living reefs. Alacran Reef thus gives us an easy explanation of atolls, apparently formed in areas of elevation; I look upon the structure of this

interesting reef as a sort of epitome of the mode of formation of the great Florida Reef and of the Bahamas Bank. Taken in connection with its position on the Yucatan Bank, it will perhaps explain the mode of formation of the greater part of the Florida peninsula as connected with the bank lying to the westward of the mainland and to the northward of the Florida reefs.

The specimens thus far obtained from the rock composing the Yucatan plateau consist of the same limestone as those of the great Florida Bank; and there are forming upon it, though to a much more limited extent, patches of reefs near the thirty and twenty fathom curve, such as the Shoals, the Triangles, Cay Arenas, the Arcas, the Madagascar, English, Alacran, and the fringing reefs of the eastern edge of Yucatan, that extend along the Mosquito coast to the central part of Central America.

It is evident from the above that we need not refer the atoll-shaped form of this reef (Fig. 44) to the subsidence of the Yucatan Bank as a whole, since the action of the prevailing winds and currents would account for all the existing phenomena. The decay of the animals living upon the great plateau, added to the deposition of all the animal life brought to it by the currents, would explain a gradually increasing elevation of the surface till the level was reached at which reef-building corals could flourish, and at which a reef would naturally be formed. Darwin has noted the close resemblance between encircling barrier reefs and atolls. It seems to me that the structure of the Marquesas (Fig. 44) and of Alacran proves conclusively that not one point of difference exists between a barrier reef and an atoll. Darwin has also called attention to the fact that in shallow seas, such as the Persian Gulf and parts of the East Indian Archipelago, the reefs lose their fringing character and appear as irregularly scattered patches, often covering a considerable area; and he also observes that many reefs of the West Indies have been formed in like manner upon large and level banks lying a little beneath the surface, — banks which he believes to have been caused by the accumulation of sediment. Such patches of reef-building corals would seem, from their analogy with the Tortugas, to be the beginning of more extensive reefs.

FIG. 44.—SKETCH MAP OF ALACRAN REEF AND OF THE MARQUESAS KEYS.

While on the way from Key West to the Tortugas we stopped at the Marquesas,[1] which are grouped as a circular ring of islands. Their formation has undoubtedly been identical with that of the great Alacran Reef; and from the fact that no corals are now found living on their weather side, these islands must have assumed their present shape at the time when their weather side made a part of the outer reef in connection with the islands of Key West and the other keys, previous to the formation of the present growing reef, or while the latter existed only in the shape of a submerged reef several fathoms below the surface. The plan and section of the Marquesas Keys (Fig. 44) show the formation of the keys on a knoll rising from the general platform of the surrounding reef plateau. This knoll has undoubtedly been built up, as were the Tortugas, from the remains of the corals which once lived upon its face and surface until the formation of the outer reef shut out the prevailing easterly winds, and the corals were killed through the accumulation of silt upon them.

The filling of a lagoon like that of the Marquesas must be a slow process, for we find the water of the inner lagoon deeper than that of any part of the reef immediately surrounding the outer slope. We can imagine that when the outer ring of the reef surrounding the inside lagoon is once completed, or nearly so, the enclosed calm area is so placed as to be subject to but few disturbing agencies, and is practically excluded from receiving any appreciable amount of sediment from the water of the outer reef, since the lagoon connects with the surrounding waters only by the narrow passages which form the channels between the lagoon and the main channel. Whether the removal of the dead coral rock from the interior of the lagoon of an atoll, by the action of the current through the narrow connecting channels, and by the solvent action of the carbonic acid, will sufficiently explain the great depth of the interior lagoon seems somewhat doubtful. The mud of the interior of the Marquesas atoll was found to be calcareous, as is practically all the mud which forms the extensive mud flats to the northward of the keys. This mud is, however, generally covered by a thin dark-

[1] See Bull. M. C. Z., V. No. 6. Letter No. 2, July, 1878.

colored layer of decomposed vegetable and animal matter. The Marquesas are covered by a thick growth of mangroves.

Judging from my examination of the Tortugas reefs, it would seem that corals do not thrive below a depth of from six to seven fathoms. It is, of course, impossible to determine whether that is their bathymetrical limit, or whether they are killed by the accumulation of ooze in the channels and adjacent slopes. We find them confined, however, to the same shallow depths, along the whole of the main reef to the northward (Agassiz). Captain Moresby also has shown that at a depth of ten fathoms in the Maldive and Chagos archipelagoes the masses of living coral are scattered at greater distances with intervening patches of smooth white sand, and that at a slightly lower depth even these patches merge into a smooth steep slope wholly bare of coral. All the evidence accumulated by Dana, Darwin, Ehrenberg, Quoy, and Gaimard tends to show that the limit of reef-building corals is found at about twenty fathoms. On the Yucatan, as on the Florida Bank, the conditions favorable for coral-reef growth have been produced, not by the uplifting of the continent, but by the gradual rising of the bank itself in consequence of the accumulation of animal *débris* upon it. The requisite level once attained, reef-building corals (Fig. 45) would first establish themselves on such spots as were most favorably situated with reference to currents and prevailing winds, both of which are essential to their healthy growth, and thus the reef would be begun.

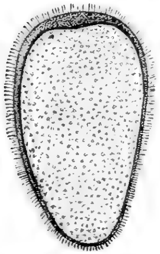


Fig. 45. — Pelagic Porites Embryo, magnified.

How far the growth of corals is affected by such local conditions is perhaps nowhere better seen than in the smaller West Indian Islands. On the eastern side exposed to the prevailing trade winds and washed by the great equatorial currents, the corals flourish, while on the lee side they do not exist at all. The whole eastern coast of Honduras, of Yucatan, and of Venezuela, exposed to the same action and washed beside by the Gulf Stream, is studded with coral reefs. To the action of the Gulf Stream on the south coast of Jamaica and of Cuba we must ascribe the presence of extensive coral reefs, and to the same cause is undoubtedly due the great San Pedro Bank. The

fringing reef which skirts nearly the whole northern coast of Cuba is in a less flourishing condition than the Florida Reef on the opposite shore, which is reached not only by the main current of the Gulf Stream, but also by the prevailing winds. The circular outline of the main reef is readily explained by the action of the Gulf Stream, which sweeping along the steep edge of the southern extremity of the great Florida plateau carries with it a superabundance of animal life, and gives the general direction along which the conditions most favorable to the luxuriant growth of corals exist when once the proper depth has been reached.

For a similar reason, corals are found alive only on the edges of the Great Bahama Bank, where they are subjected to the beneficent action either of currents or of winds, that drive the silt clear of the growing corals, and bring an abundant supply of food. The same causes which have formed the great mud banks to the northward and westward of the Florida Reef have, in the case of the Bahama Banks, formed the immense sand flats and shallows which are fringed by living corals on the east and west. They owe their existence, on the one side, to the wash of the northerly trend of the great equatorial current, and to the action of the trades; on the other, to the clearing action of the Gulf Stream. It must also be remembered that the Bahama plateau was originally joined to Florida, as part of the great fold which built up the framework of that peninsula, and that it was also connected at one time with the island of Cuba. It was also united with the reefs, now elevated to eleven hundred feet, which joined the eastern and western islands in more recent geological times, and formed, before the tertiary, the two extremities of Cuba. On the southern side the reefs are still in full activity, while on parts of the northern coast, in the vicinity of Havana, they have been elevated to a height of no less than one thousand or eleven hundred feet, while the present barrier reef of the north shore of Cuba forms an immense reef, extending with scarcely a break from Cape San Antonio to the eastern edge of the old Bahama Channel.

The Bahama plateau we may also fairly assume to have been built up, little by little, from its original level, by the accumulation of limestone formed in great part from the bodies of the

mass of animals which undoubtedly flourished upon the great submarine plateau at a time when the Gulf Stream found its way out of the Gulf of Mexico with less velocity than it now has as it passes through the narrow Straits of Bemini. At that time it spread itself fan-shaped over the southern part of Florida and the Bahama Bank, and flowed more gently northerly and easterly along the coast, with the additional reinforcement of the westerly equatorial, flowing north of the Great Antilles to the eastward of Cuba. The Bahama Bank then probably consisted of a series of banks like Salt Key Bank, separated by channels like the Santarem and St. Nicholas, which were undoubtedly kept open by the same currents as now form the Old Bahama Channel. These channels, like those between the keys on the Florida side, have gradually become filled with the detritus driven into them by the trade winds, until the bank has been formed in its present state of consolidation. Yet it must not be forgotten that, while in the western part of the Caribbean, the Gulf of Mexico, and Florida a dead level prevails, at Havana, Hayti, and Barbados we have reefs elevated to a great height, and others at considerable elevation on certain of the Greater and Lesser Antilles.

The somewhat capricious distribution of coral reefs may perhaps be explained by the action of the great equatorial currents. The larger reefs occur in regions to which these currents bring in the track of their course abundant supplies of food for the reef-building animals. On the eastern coast of Africa, of Central America, or of Australia, for instance, extensive colonies of coral reefs flourish, while on the western coast of the same continents, in similar latitudes, but not bathed by such powerful equatorial currents, the supply of food seems insufficient for more than the isolated patches of corals existing there.

Other naturalists, as Semper[1] and Murray,[2] and later, Studer, have already attempted to explain the formation of coral reefs, in part at least, on grounds differing essentially from those to which Darwin ascribed them, and similar in the main to those

[1] Semper, C. Zeits. f. Wiss. Zool., 1863, XIII. p. 558.

[2] Murray, John. Proc. R. S. Edinb., No. 107, 1880, X. p. 505, On the Structure and Origin of Coral Reefs and Islands.

here brought forward. Mr. Murray's "observations of the reefs at Tahiti[1] support the view that they have been built from the shore seawards, and that the lagoons have been and are still being formed by the removal of the inner and dead portions of the coral reef by the solvent action of sea-water. . . . The food supply for the masses of living coral on the outer slope of the reef is brought by the oceanic currents sweeping past the islands, — a fact which explains the more vigorous growth of the reef on the windward sides. It is maintained by Mr. Murray that the whole of the phenomena of the Tahiti reefs may be fully explained by reference to the processes at present in action, and without calling in the aid of subsidence, as is done by Darwin and Dana; and it is further argued that the form of atoll and barrier reefs generally can be explained on the same principles."

Undoubtedly, Darwin's theory of reef formation presents a sound and admirable exposition of the grander causes which have brought about the elevation or subsidence of large tracts to a level favorable for coral growth; but at the time he wrote upon this subject, the formation of extensive limestone banks, built up by the animals living on the bottom, and constantly strengthened and increased by the attendant phenomena of winds and currents, was little understood. These facts have been brought into notice and emphasized by recent deep-sea explorations. Darwin, however, when examining maps of the West Indies, had been struck by the probable connection between the areas of deposition of the great banks marked upon the charts and the course of the sea-currents. He naturally explained the steep slopes, abruptly dropping from comparatively shallow plateaux to great depths, by what is known to occur wherever great masses of sediment are found, and he therefore considered these plateaux to be submerged mountains. Such they are, in a certain sense; not wholly built, however, as Darwin supposes, of sediment, but in great part also of the remains of the innumerable animals living and dying upon them. The nucleus of these banks has probably been formed around the shores of promontories subjected to the most active play of the great oceanic currents.

[1] Voyage of the "Challenger," Narrative of the Cruise, p. 781. 1885.

At the time when Darwin wrote, and when we knew little of the limestone deposits formed by the accumulation of the *débris* of mollusks, echinoderms, polyps, and the like, upon folds of the earth's crust, the formation of the basal parts of barrier reefs was difficult of explanation. The evidence gathered by Murray, Semper, and myself, partly in districts which Darwin had already examined, and partly in regions where his theory of reef formation never seemed to find its proper application, has in a measure removed this difficulty. It all tends to prove that we must look to many other causes than those of elevation and subsidence for a satisfactory explanation of coral-reef formation. All-important among these causes are the prevailing winds and currents, the latter charged with sediment which helps to build extensive plateaux from lower depths to levels at which corals can prosper. This explanation, tested as it has been by penetrating the thickness of the beds underlying the coral reefs, seems a more natural one, for many of the phenomena at least, than that of the subsidence of the foundation to which the great vertical thickness of barrier reefs has been hitherto referred. Still, it is difficult to account for the great depth of some of the lagoons — forty fathoms — on any other theory than that of subsidence.

If, however, we have succeeded in showing that great submarine plateaux have gradually been built up in the Gulf of Mexico and the Caribbean by the decay of animal life, we shall find no difficulty in accounting for the formation of great piles of sediment on the floors of the Pacific and Indian Oceans, provided these banks lie in the track of a great oceanic current. Certainly the coral reefs of the Caribbean and the Gulf of Mexico, of Florida and the Bahamas, are distributed upon banks which lie directly in the path of the great Atlantic equatorial currents and of the Gulf Stream, — banks which we know to have been formed by the agency of these currents.

The fact that the coral reef at the extremity of Florida is the most recent of the coral formations found on the Florida shores plainly shows that these reefs, as well as those of Yucatan, Cuba, the Bahamas, and the Caribbean Sea, though not all of the same age, were yet of modern origin, since we find them

still in an active state of formation. Even the elevated reefs of Cuba and of the other West India Islands, though older, probably belong, nevertheless, to the most recent deposits of the kind we know. The difficulty of explaining the constant renewal of the coral faces of the atolls of the Pacific, and their present condition, on the supposition of their having existed from the time of the early tertiaries, was one of the main causes which led Darwin to seek for some other agency, like subsidence, to explain the renovating process of the original structure. In some instances coral reefs have unquestionably been uplifted. I have seen the elevated reefs of Cuba, of San Domingo, and other West India Islands, and of Barbados[1] (Figs. 39, 46), which are perhaps the most striking examples of

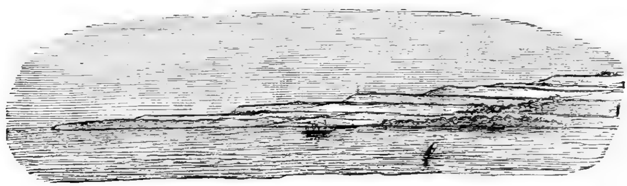


Fig. 46.—Terraces near Fort Charles Light House, Barbados.

elevated reefs. They are too well known to need more than a passing notice here. The terraces they form show plainly the successive stages of arrest in the agency of elevation, and there is no difficulty in accounting for their existence especially in a volcanic region like the West Indies; but that there should have been an extensive area of subsidence, in which the rate of subsidence was so evenly balanced with the rate of coral growth as to create and maintain the necessary conditions for reef formation, is less easy of explanation.

The cap of rhizopod earth for which Barbados is noted dates back to a time when the volcanic centre round which the coral reefs have grown in more recent times was still at a considerable depth below the level of the sea. This large accumulation of rhizopodial earth is an excellent example in favor of the theory

[1] The trachytic cone forming the base upon which the successive terraces of Barbados have been elevated is seen to crop out on the surface in the northeastern part of the island.

of Mr. Murray, that the inorganic material held in suspension in the sea became precipitated on the sides of volcanic peaks or slopes, and thus forms little by little the base or plateau upon which coral reefs eventually grew. If this be true, it is not necessary to resort to Darwin's theory of extensive areas of elevation or of subsidence in order to explain the formation of atolls or of fringing reefs. In the tropics and in regions situated in the path of great oceanic currents which carry along their course an immense amount of pelagic life, serving as food for the animals living upon the bottom, we have all the elements of the gradual accumulation of submerged land, which, when it rises to a certain level, becomes the foundation upon which reefs are formed. In fact, as has been well pointed out by Mr. Murray, we should have in an area of elevation as well as one of subsidence all the elements necessary for the construction of atolls.

In a very interesting article on the Bermudas, Rein[1] has taken very much the same view of their gradual building up, and explains the present condition of things by causes greatly differing from those adduced by Darwin to account for the apparent atoll shape of the groups.

The islands composing the Tortugas (Fig. 38) are Loggerhead, Bird, Garden, Long, Sand, Middle, and East Keys. These are always above the level of the sea, while Southwest Key and Bush Key are exposed only at low water, and North Key and Northeast Key have disappeared. These insignificant islands are the outcrops of extensive submarine banks. Loggerhead Key, not more than three fourths of a mile in length, is the top of a bank about five miles in length, extending to the three-fathom line, with an average width of three fourths of a mile, and has extensive coral sand flats running in prolongation of the northern and southern extremities of the key. Between this and the Garden Key and Long Key Bank, there are a few shoals running more or less parallel with Loggerhead Bank, the largest of which are Brilliant and White Shoals. Garden Key and Long Key Bank form a rectangular shoal of nearly the

[1] Rein, J. J. Beiträge zur Physikalischen Geographie der Bermuda Inseln. Bericht. Senckenb. Naturf. Gesell., 1869–70 (Mai, 1870), pp. 140–158.

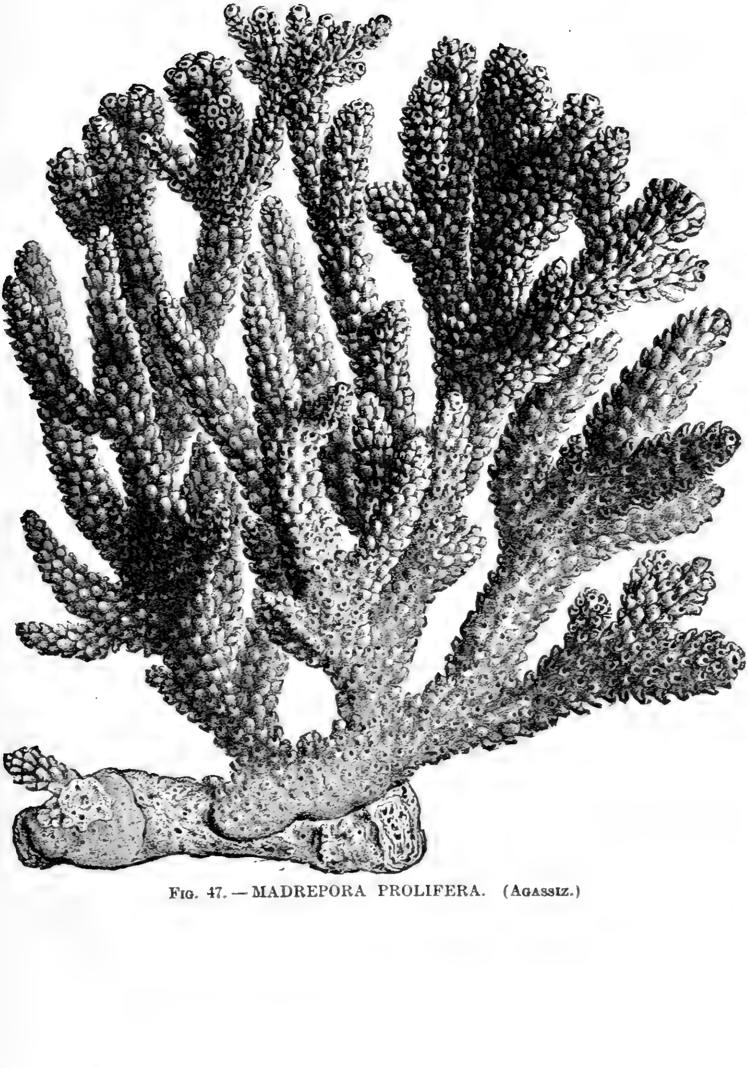


Fig. 47. — MADREPORA PROLIFERA. (Agassiz.)

same length as that of Loggerhead, with an average width of nearly two miles, the great sand flats of this shoal being those of the Long and Bush Key tract. The Southwest Channel, with a depth varying from ten to twelve fathoms, separates Loggerhead Bank from the Bird, Garden, and Long Key Bank. This, in its turn, is separated from the still greater North, Northeast, East, and Middle Key Bank by the Southeast Channel, with a depth of about nine fathoms, while the Northwest Channel separates Loggerhead Bank from the North Key Bank, with an average depth of from seven to ten fathoms. The Eastern Bank is irregularly horseshoe-shaped, convex to the east, and partly surrounds a great interior bay, which has an average depth of about seven fathoms. The flood tides run from the south through the Southwest and South channels in a northeasterly direction, the ebb tide flowing in the opposite direction. The strongest tidal current passes through the Southwest Channel.

An examination of sections of the Tortugas from the west to the east shows the gradual rise of the mound forming the Tortugas, as we pass from the west side of the Loggerhead Bank to a line extending through the southwest slope of the same bank, and across to the main bank of the group; the mound falls slowly on the eastern slope as we cut across the east end of East Key Bank, till we finally come to the low elevation forming the southeast slope of East Key Bank. The action of the tides through the Southeast and Northwest channels is well shown in the fact that they keep open the passages between Long Key and Loggerhead banks, and between the former and North Key Bank, and also the secondary channels separating Bird Key, Garden Key, and Long Key. These are undoubtedly the last traces of the deeper and wider channels, probably once running parallel to the Southeast Channel. They have gradually been filled up since the sand flats of Bush Key began to form, so that the free circulation of the tides through them has been prevented. The presence of a few large heads of mæandrinas and astræans, as well as the luxuriant growth of *Madrepora prolifera* (Fig. 47) near low-water mark, on the two sides of these channels, now changed into sand flats, seems to indicate a

more active tidal circulation through them formerly than is now taking place. An examination of the cross-sections in the direction of the prevailing winds, and in the direction of the tides, shows at a glance the mound-shaped mass which forms the base, rising from the general level of twenty-five to thirty fathoms, with its abrupt side facing the east. There are also seen the deep furrows, more or less broad, which have been scooped out of this mass by the action of the currents, such as those passing through the Southwest Channel.

The corals which give to the reefs their peculiar physiognomy are the extensive patches of Madrepora (principally *M. cervicornis*), the clusters of the two common species of Porites (*P. furcata* and *P. clavaria*) (Fig. 48) covering more or less the shallow tracts of coarse sand, and *Mæandrina areolata* growing between the patches of marine lawns formed by a species of Thalassia, with occasional patches of Anadyomene. In other parts of the reefs large holothurians (Mülleria) lie scattered on the bottom, while in somewhat deeper regions are pockets filled with large Diadematidæ. Immense masses of nullipores (Udotea and Halimeda, Figs. 49, 50) and corallines grow on the shallowest flats, on the tops of the branches of madrepores which have died from exposure to the air, either because they have grown up to the surface and so have become exposed by extreme low tides, or because strong winds have blown the water from the flats. The destructive effect which an extremely low tide has on a growing reef is well shown on the flats to the southward of Fort Jefferson, where the upper part of the branches of a certain size reaching up to a given level are frequently killed off by low tides. Exposure to the action of the sun even for a very short time is sufficient to kill them. The extreme sensitiveness of all corals to atmospheric action is well known, so that it becomes plain, as has been


Fig. 48. — Porites clavaria. (Agassiz.)

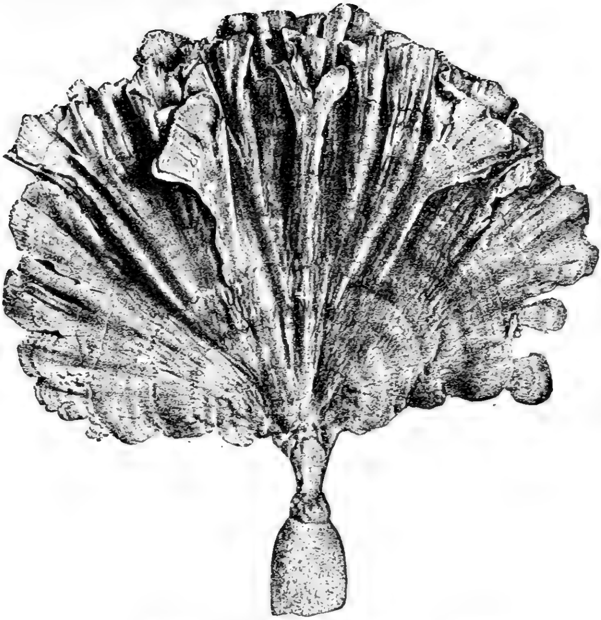


Fig. 49. — UDOTEA FLABELLATA. (Agassiz.)

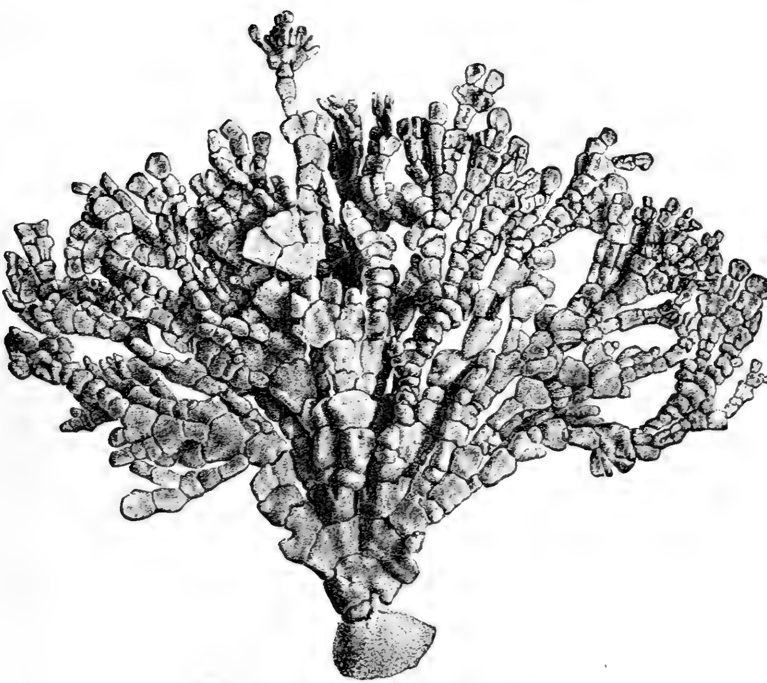


Fig. 50. — HALIMEDA TRIDENS. (Agassiz.)

stated already by Darwin, Dana, and others, that no coral reef can grow above the level of the lowest tides, and that all subsequent additions of material must be due to accumulation of sediment transported by the action of the tides and prevailing winds.

Next come the clusters of coral heads, huge masses of astræans and of mæandrina, very limited in their distribution at the Tortugas, as well as the more or less extensive patches of *Madrepora palmata* (Fig. 51), and finally what is known as broken ground, namely, the outer edge of the reef occupied mainly by clusters of gorgoniæ (Fig. 52), which also reach upward into the shallower region. Occasional patches may be seen of astræans, madrepores, and other reef-builders, which have extended below the depths at which they generally flourish, where they are soon killed or choked by the accumulation of fine coral sand and coralline sand or ooze of the deeper waters. This sediment fills the broad and narrow flat channels dividing the three great banks which compose the Tortugas, or separate the inner shoals, banks, and islands. Finally come the lines of broken coral heads and branches, mixed with dead corallines, shells of mollusks, old serpulæ tubes,[1] gorgoniæ stalks, and the like. These form a low dike, as it were, to be little by little pounded up by the breakers into smaller fragments, and carried, either by the winds, or waves, or currents, into the interior of the reefs, there to form sand flats of more or less coarse materials, until on the western faces of the banks the finest detritus is deposited in very steep slopes, constantly shifting like those of sand dunes, and, like them, running forward and backward at the will of the winds and waves. This continues until the particles have become cemented together by the action of the carbonic acid contained in excess in the salt water surrounding the reefs, and by the gluing of the slight amount of animal matter which holds these particles together. Some of the slopes (according to General Wright, of the Engineers) are as great as thirty-three degrees.

All this fine material, composed of fragments of every animal

[1] Serpulæ often form incrusting masses of considerable extent, acting, as has been noticed by Darwin, much as the patches of nullipores do in protecting decayed and dead corals from being too rapidly broken to pieces by the action of the waves.

and plant with a calcareous skeleton, of course prevents the growth of corals in positions which are not well scoured, either by the action of the tides or by that of the prevailing winds. The corals when alive are gradually buried under this mass of material constantly passing over them, and held in suspension. They flourish, therefore, only where the disturbing elements are reduced to a minimum; namely, on steep banks, or on the slopes which are scoured by tides, or on flats at considerable depths, over which a large body of water can freely pass, whether brought by the tides or driven by the winds. In such cases the corals can grow gradually towards the surface as fast as the sediment deposited has closed up the circulation of the lower levels. The quantity of calcareous matter held in suspension in the water in the vicinity of a reef, and on the reef itself, is very great. The breakers pounding upon the exposed slopes of the reefs destroy, even on calm days, large quantities of corals which have been weakened by the borings of mollusks, annelids, echinoderms, and sponges. On windy or stormy days the powdered fragments are driven far and wide, turning the surrounding water to chalk color for a considerable distance from the reef. It is not an uncommon thing, after a blow, to come upon this water discolored by the fine calcareous silt, to a distance of six to ten miles from the outer reef. After a prolonged storm I have seen between two and three inches of fine silt deposited in the interval between two tides. The limitation of coral-reef growth to shallow depths may be due to the fact that the ooze held in suspension rapidly sinks towards the bottom, the surface water remaining clear. The rapidity with which the corals are choked readily explains why they must of necessity have a limited vertical distribution depending upon local causes. This is well shown along the sections of the Tortugas. Off the Marquesas, and along the line of the main reef, we find corals living and flourishing at a much greater depth, and there seems to be no simpler explanation of the limited bathymetrical range than that of the baneful action of the silt near all reefs. That the silt is carried on the bottom by currents and waves is well known, and on the bottom of the Gulf Stream, to the north of the Straits of Bemini, we have a huge muddy bot-

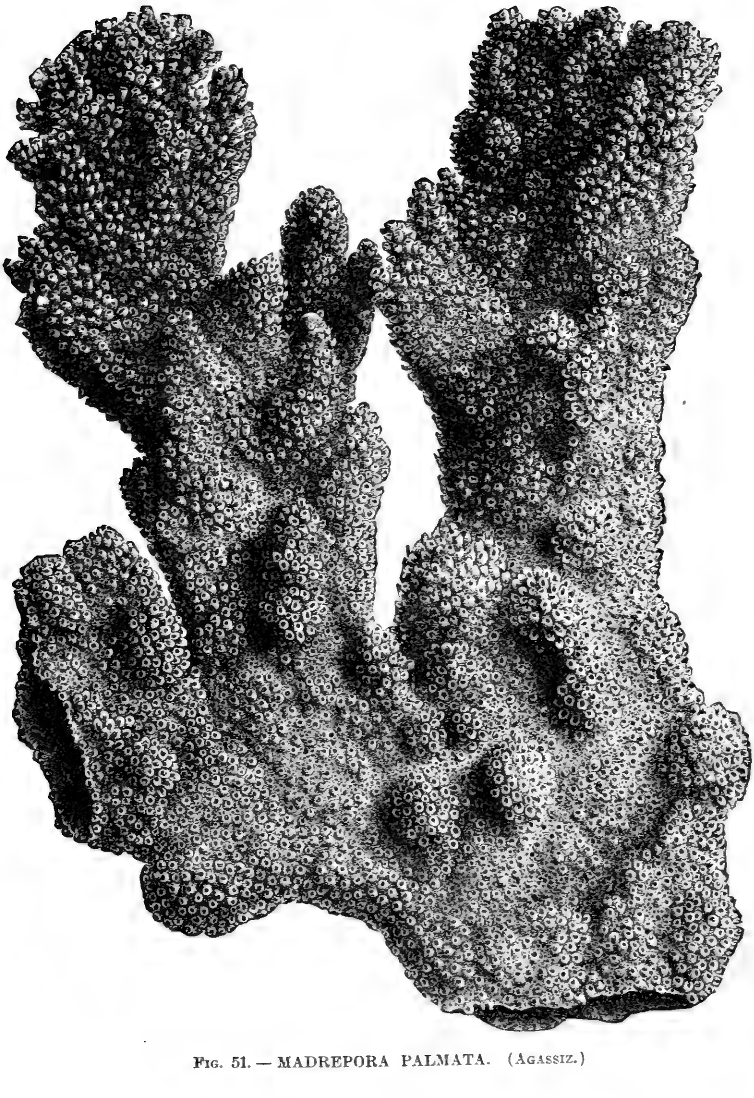


Fig. 51. — MADREPORA PALMATA. (Agassiz.)

tom river carrying its silt to the steep slope south of Hatteras, depositing occasionally a few patches of green sand along the sides of its course, while the upper waters are perfectly clear and of the deepest blue.

Corals alone cannot supply all the sand we know to be carried by the Gulf Stream. We must add to this the mass of silt, mud, and sand which come from pelagic animals, and which is distributed by the winds and waves, to be spread uniformly over large areas, as is well shown from the distribution of the immense mass of calcareous ooze over the whole of the bottom between Florida and Cuba. This mass undoubtedly owes its existence in part to the silt which the Gulf Stream brings from the southeastern edge and slope of the Yucatan Bank, in part to the accumulation of the pelagic fauna which the same great current sweeps along its course. The amount of work done by the animals living upon the reef in preparation for the grinding process of the breakers is very great. All writers upon the reefs have referred to the destructive agency of boring mollusks, annelids, and echinoderms, that riddle the coral branches and heads with holes, and prepare the way for their fracture into larger or smaller fragments.

The echinoderms found upon the flats seem to live almost exclusively upon the organic matter and foraminifera they find mixed with the coral sand, upon which they feed, and which fills their digestive cavity. Their action, however, while an important one, in that they reduce the sand to a smaller size, is yet very slight as compared to the action of the breakers upon the sea-face of the reef. Darwin and others have referred to this agency of the echinoderms as one among those at work in triturating the corals. By some observers, these animals are supposed to be browsing on the living coral. This is not the case either with holothurians and Diadematidæ or with clypeasteroids: living on flats, they swallow the sand as they find it. But with Cidaris and Echinometra, which dig out holes in the coral rock, the case is different. H. H. Guppy has also observed the holothurians full of sand on the flats of the reefs of the Solomon Islands.

The Loggerhead, Bird, and Bush Key banks, which protect

each other to a certain extent from the action of the strong winds opposed to the prevailing trade-winds, present a more normal growth than that of the North Key Bank, which is particularly exposed to the full fury of the northers; they must counteract to a great extent the action of the trade-winds. The distribution of the broken ground, the position of the masses of *Madrepora cervicornis*, and the trend of the sand flats, all alike show the conflicting action to which the two slopes of this great bank have been subjected. This counterbalancing action of the northers and of the trade-winds is also well shown by its effect on the position of the islands themselves. During the prevalence of southeasterly winds, East Key, Sand Key, and Middle Key extend bodily to the westward, the materials for their growth being washed from the eastern shores. The opposite takes place during the prevalence of northers. The outline of Loggerhead Key is also constantly shifting, and according to the officers of the Lighthouse Board, none of the landmarks furnished by these islands can be relied upon in the location of buoys.

What takes place upon the shores of the islands also takes place, of course, upon the flats. Owing to the action of the winds and waves, the whole mass of the surface of the reef is kept in more or less active movement, according to the depth of water on the flats and to their position. The coarser materials covering the flats and shore lines, and made up of large-sized fragments, are gradually changing to the coarse sand which forms the flats nearer the outer edge of the reefs; and this, in its turn, is changed into the fine silt which fills the channels, and eventually limits the growth of the corals to regions where they can find permanent lodging, and are not immediately under the influence of this shifting sand and silt. The quality of the sand forming the beaches at different points on the keys and flats depends entirely on its position. It will be coarser or finer, according to the exposure of the beach, and the finest sand is found in the most sheltered places, where the silt has free chance to settle. (See Fig. 53 for a view of a characteristic coral sand beach at Key West.) The scarcity of fossils in the coral limestones of the reef has already been dwelt

FIG. 52.—RHIPIDIGORGIA FLABELLUM. (AGASSIZ.)

upon, and their absence is readily accounted for by the constant disturbance of the shore-line deposits, which reduce little by little the larger fragments of shells and corals, or echinoderms, to a breccia, or again to oölite or fine sand. This is nowhere so well seen as on the shore line of Key West to the north of Fort Taylor. (Fig. 53.) There the outer reef is sufficiently distant to allow waves of considerable size to break upon this coast, and then strike to a low line of shore rocks. These rocks are completely riddled by larger or smaller cavities made by boring mollusks, annelids, sea-urchins, etc., or left by fossils or fragments of corals which have fallen out. Thus weakened, large masses are easily undermined by the water, which washes around them with considerable force. They fall off, become then broken into smaller and finer pieces, which are again reground in their turn, and are finally either re-soldered into finer breccia or coarse oölite, or into the finest oölite or sand, according to the composition of the rock. This is then cemented again to the shore line, forming a new line, more or less regularly stratified, dipping towards the sea, and, when exposed to the action of the air, soon coated with a thin film of hard limestone. This hardens, and forms the ringing crust of the rocks found everywhere on the keys. This coating is formed with great rapidity. An exposure between two tides is sufficient to form such a thin coating, as I have repeatedly had occasion to observe in the deposition of finer oölitic sands which fill the rock-pockets just within reach of the waves at high tide. A process of undermining similar to what has been observed at Key West takes place along all the coral-rock shores which happen to be exposed to the action of the sea. From the description of Rein and others, this undermining action, operating on a very much larger scale on æolian deposits of considerable altitudes, must be the principal agent in the formation of some of the peculiarly characteristic features of the Bermuda Islands. On the east and west shore of Loggerhead, near the northern extremity, we can trace admirably the successive layers of the coral limestone which have been deposited and have had an opportunity to harden between the tides, forming what appear to be stratified beds, with their outcrops running as a gen-

eral thing parallel to the bend of the shore or at a slight angle from it, and dipping on the one side to the eastward and on the other to the westward.

The bank to the west of the Tortugas has large heads of astræans (Fig. 54) and madrepores growing up on it at a depth

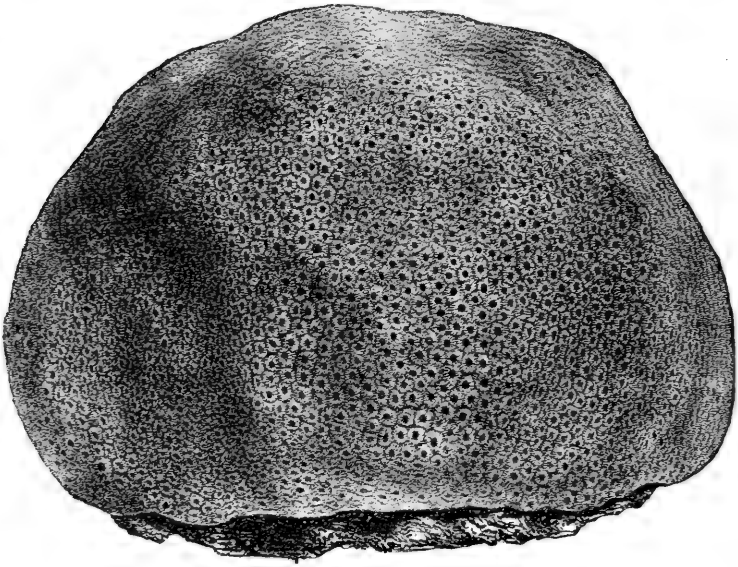


Fig. 54. — Orbicella annularis. (Agassiz.)

of from six to seven fathoms. Gorgoniæ are still found at a somewhat greater depth. This bank is an excellent specimen of an isolated coral patch, such as must have formed the basis of all the keys and reefs. In time it will undoubtedly form a new reef, flush with the surface, to the westward of the Tortugas. The greatest depth at which reef-building corals have been observed to grow is in the Southwest Channel on the steep banks of White Shoal, and in the channel to the southwest of Bird Key, where madrepores grow to a depth of about ten fathoms.[1] As a general rule, however, the corals are choked

[1] Murray found off the slope of the reef at Tahiti that "the whole of the space from the edge of the reef to a depth of about thirty-five fathoms was covered with a most luxuriant growth of corals, with the exception of one or two small spaces where there was white coral sand."

Fig. 53.—CORAL SAND BEACH SOUTH OF NAVY DEPOT, KEY WEST.

below six fathoms by the ooze, and their place is taken by gorgonians.

All estimates of the age of the southern extremity of Florida, or of the reef alone, must necessarily be very defective. The great age assigned by Professor Agassiz to the northern part of the peninsula may not be exaggerated, if it be understood as including the time at which the Vicksburg limestone forming its backbone was deposited. But the extension of the coral reefs proper so far north in Florida has never been proved. The rate of growth of the reef-builders is very rapid, and it is quite possible that the reef-builders of the Florida Reef began at once all along the line extending from Key West to Cape Florida, and quickly reached the surface, forming at first a barrier somewhat less compact than the present line of reef. Uncertain as we are respecting the time at which the various parts of the reef reached the surface, we can only say that in Florida, limiting the estimate strictly to the depth at which corals grow, it would probably take from one thousand to twelve hundred years for corals to rise from the seven-fathom line to the surface. This would give us no clue whatever to the actual age of the reef, because it is difficult to determine how far the width of any coral reef is due to the growth of coral. But supposing the reef to have an average width of half a mile, and its lateral growth to be say four or five times more rapid than its vertical increase, we should get at least twenty thousand years as the age of the outer reef. It is quite possible for a great width of reef to be forming at one time, and to spread laterally with rapidity if the plateau upon which it grows is of the right depth. Take, for instance, the width of flats upon which madrepores flourish. A plateau at favorable depth would very soon be covered by them; they would spread rapidly until they reached the edge beyond which no corals could thrive, on account of the depth.

Thus we see, from the sections and a study of the distribution of the corals, that at the present day material is constantly added to the knoll forming the Tortugas; that this material is derived either from the animals and plants living upon the reef, or from the pelagic animals which die while passing through

the channels; and that we can find nowhere any trace of elevation. Here the calcareous material has evidently been heaped up to its highest point by the influence of the waves or winds. Furthermore, we see growing to the westward of the Tortugas a knoll similar to that which has formed the Tortugas themselves, and which will form, in the course of time, an island or a series of islands like them to the westward. It is further evident, also, that the Alacran Reef has been built up in the same way, and that its peculiar atoll shape is due to the action of the prevailing winds and currents, and not to any subsidence of the great Yucatan plateau.

The character of the fauna and flora of the Tortugas is interesting as corroborating the comparatively recent age at which the reef has been formed. We find, as we go north along the keys, that the nearer we come to the mainland of Florida, the greater the number of plants characteristic of the mainland. As we reach islands more or less inaccessible, or islands merely formed by flats which have reached low-water mark, the vegetation consists almost wholly of mangroves. Yet at the Tortugas, in spite of the narrow channel which separates them from the Marquesas, I saw but a single diminutive mangrove plant, while a few bay-cedars, as they are called, a vine with a thick white flower, and Bermuda grass have alone found their way there, although the Tortugas are in the direct line of the prevailing winds from the Marquesas. One of the species of land shells common at Key West has already found its way to the Tortugas. The group is visited by pelicans, cranes, humming-birds, plovers, and a few land birds. It being the winter season when I visited the place, the insects were few in number. No terrestrial reptiles have been found on the Tortugas, while at Key West there are many of the frogs, toads, lizards, and snakes characteristic of the southern spit of the mainland, — all this showing that the Tortugas reefs have not been above the level of the sea long enough to have received as yet the fauna or flora characteristic of the more northern line of keys.

The explanation given here of the formation of huge deposits of limestone from the limestone carcasses of invertebrates takes

for granted that the most favorable conditions for their support exist; and this condition we assume to be an abundance of food, brought to them by the great oceanic currents passing over the regions where these submarine plateaux are forming. We know as yet too little of the fauna of the oceanic basins to be able to affirm how far the population of the bottom depends upon the food it receives from oceanic currents. We can only judge by analogy. No marine fauna has been explored which equals in variety or in the number of its individuals that of the Caribbean and of the Gulf of Mexico, from the depth of two hundred and fifty to about one thousand fathoms. It has proved richest in the districts most favorably situated with regard to the currents and the food supply they bring in their track. It is but natural to extend this effect to other oceanic currents, and in their track we may therefore expect to find the most favorable conditions for the support of an immense fauna. In fact, the question of food is of the utmost importance to the distribution, not only of marine, but of terrestrial animals; and the absence or presence of an abundant supply of suitable nourishment must of necessity be an all-important factor in the character and variety of the fauna of any place or period, — far more influential, perhaps, than the many obscure physical causes upon which we are so apt to explain the distribution of animal life. On the continental ledges, where the shore detritus is gradually accumulated, bringing with it a large amount of animal and vegetable food, we find the most populous fauna near the hundred-fathom line. When, in addition to the action of the influences which have accumulated the shore detritus, we have a continental shore or plateau bathed by a great and powerful current, bringing with it an abundance of pelagic life, we may expect a superabundant supply of food, and consequently a fauna of unusual richness and variety. The fauna of the Pourtalès Plateau, of the hundred-fathom slope to the westward of the Tortugas, of the northeastern slope of the Yucatan plateau, of the windward side of the Lesser Antilles, and of the continental slope of the eastern coast of the United States below the hundred-fathom line, are all examples of such districts supporting a marine fauna of sur-

passing richness. In a similar way, we may expect to find in the track of the Pacific equatorial current the most favorable conditions for the support of a rich and varied marine fauna. The "Challenger" found, perhaps, no richer dredging fields than off the coast of Japan, which lie directly in the track of the Japanese stream; the fauna of the Kuro Siwo may be considered as the Pacific equivalent of the Florida and Caribbean fauna.

In past geological times the effect of the currents in determining the distribution of the marine invertebrates must have been as marked as it is at the present day. As long as we had a great equatorial current running practically unbroken round the world, and only slightly deflected by the continental islands of Central America and of the East Indies, which stood in the path of this equatorial belt, it was natural that we should have a very extensive geographical range for all the tropical marine forms. It was only after the complete shutting off or comparative isolation of the Atlantic from the Pacific that different physical conditions began to exist simultaneously, which were of the greatest importance in reducing the supply of food to the animals on the west coast of the continental barriers, and in extending towards the north, as far as the temperature would allow, a supply of food far more abundant than that with which the fauna of the eastern coast was supplied before such a break of continuity existed. As this separation of the Atlantic and Pacific probably took place late in the cretaceous period, and was perhaps not completed till the middle tertiary, we shall naturally expect to find the marine fauna of the earlier geological periods of the Old and the New World to be very similar, and consisting of many identical species. These older faunæ flourished on the shores and continental shelves which were washed either by the equatorial currents, or by branches extending both north and south along the then existing continents and continental islands; and where we now find rich fossiliferous deposits we may feel assured that the beds at the time of their formation were either formed along a continental shelf, or lay in the track of a primary or a secondary marine current, which supplied an abundance of pelagic food indirectly necessary for the support of any rich marine fauna.

IV.

TOPOGRAPHY OF THE EASTERN COAST OF THE NORTH AMERICAN CONTINENT.

ONLY the most general features of the topography of the Western Atlantic, including the Gulf of Mexico and the Caribbean, were known before the explorations of the "Blake." The course of the hundred-fathom line from George's Bank to Cape Hatteras, the Straits of Florida and the Gulf of Mexico, was accurately laid down from the work of the hydrographic parties of the United States Coast Survey. (Fig. 55.) The hundred-fathom line indicates in a general way the true continental outline of the eastern coast of the United States. The continental slope connecting this submarine shelf with the bed of the Atlantic, and with the basins of the Gulf of Mexico and of the Caribbean, was traced in its details by the successive expeditions of the "Blake." We must except the oceanic lines run by the "Challenger," connecting Nova Scotia and New York with the Bermudas, and the Bermudas with St. Thomas.[1]

[1] "Similar investigations," says Professor Hilgard in an account of the work of the "Blake," "have since been prosecuted by Commanders Bartlett and Brownson, U. S. N., under the direction of the Superintendents of the Coast Survey, in the western part of the North Atlantic, — that great embayment, which, limited by Newfoundland on the north and by the Windward Islands on the south, might be not inaptly named the Gulf of North America. The depths and temperatures obtained by these officers, upon lines run across the course of the Gulf Stream, and connecting with those run by H. M. S. 'Challenger' in 1873, will make apparent the part taken by the Coast Survey in developing the configuration of the ocean-bed between the Bermudas and the West India Islands, and northward to the Banks of Newfoundland, and in defining the limits of the continental plateau, which, extending from the coast to the hundred-fathom line, may be described as the western rim of this great basin of the North Atlantic. . . . During the winter of 1881 to 1882 the 'Blake' was engaged in developing the limit and general character of the great Atlantic basin between the Bermudas and the Bahamas, and along the outside of the West India Islands as far to the eastward as St. Thomas. This cruise has been of great interest. The bed of

A great number of soundings, mainly along the continental slope of the New England States, were also taken by the vessels of the United States Fish Commission. Important soundings were made by the United States Fish Commission

Fig. 55. — Model of part of the Western North Atlantic.

steamer "Albatross" in the Caribbean, during the winter of 1883–1884.

Along the Atlantic coast of the United States (Fig. 56) from Cape Hatteras north to the extremity of George's Bank, the

the Atlantic is shown to have a general depth of two thousand seven hundred or two thousand eight hundred fathoms ; and depths of over two thousand fathoms are found almost if not quite in sight of most of the islands along the outside of the Bahamas, and even in the narrow passages between them."

Fig: 56.

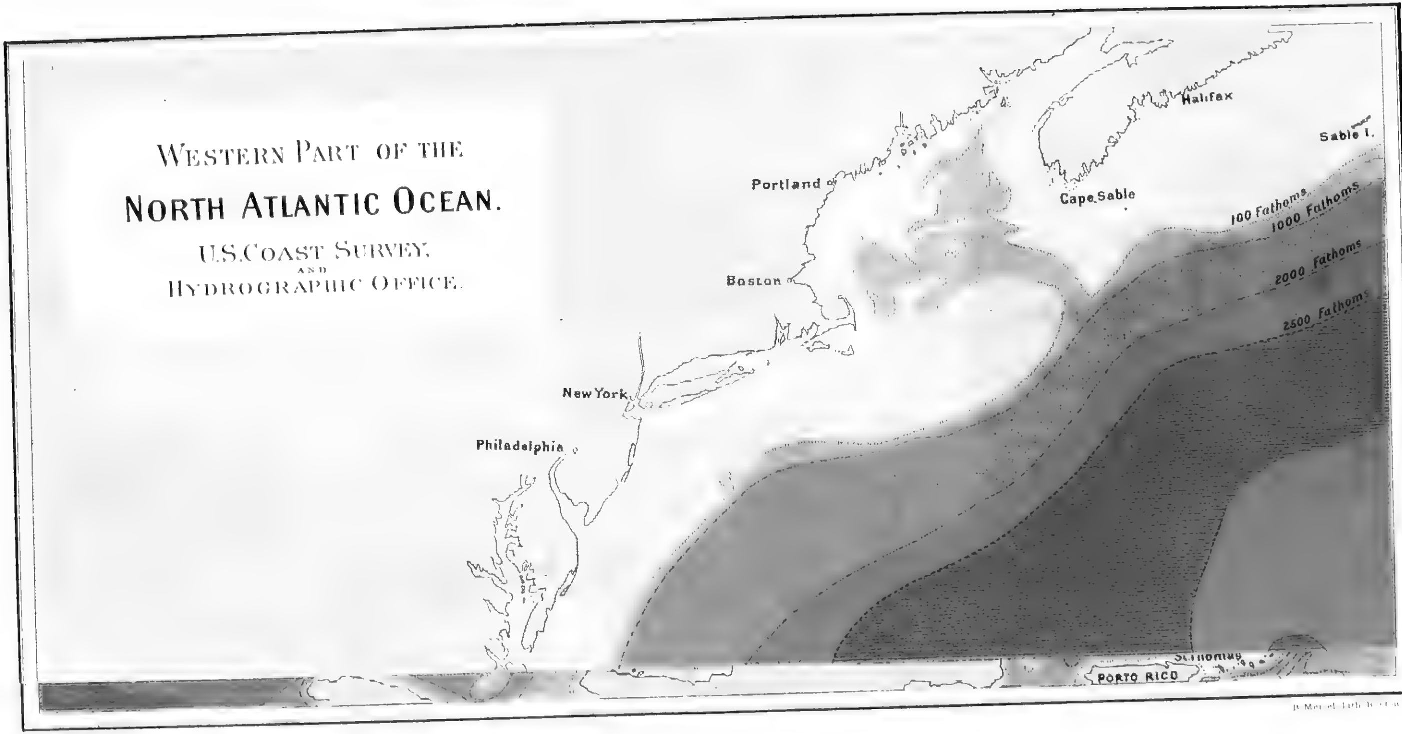
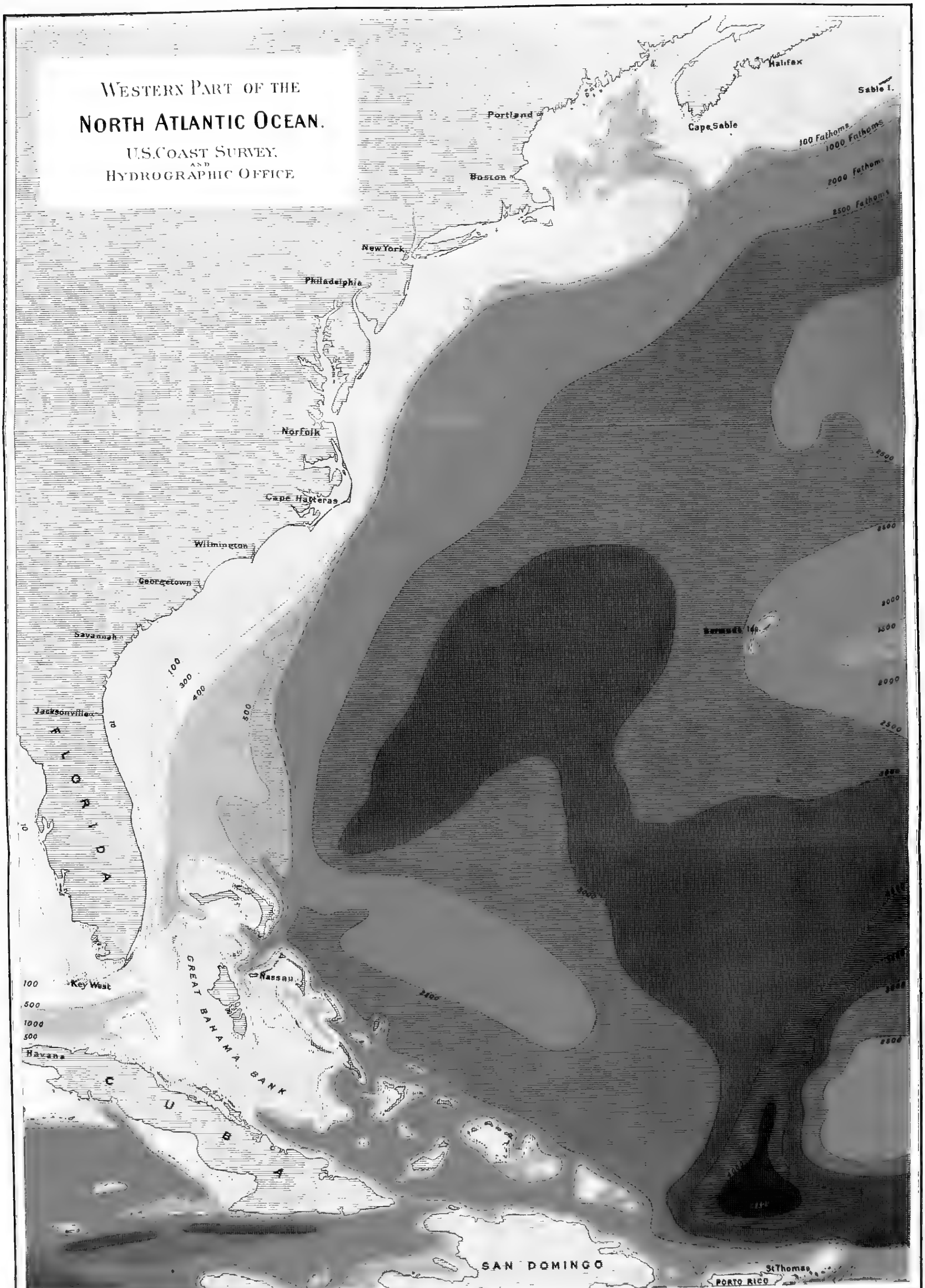

WESTERN PART OF THE
NORTH ATLANTIC OCEAN.
U.S. COAST SURVEY
AND
HYDROGRAPHIC OFFICE.
Halifax
Sable I.
Portland
Cape Sable
100 Fathoms
1000 Fathoms
2000 Fathoms
2500 Fathoms
Boston
New York
Philadelphia
PORTO RICO

Fig 56



B. Meisel Lith. Boston

continental shelf increases gradually in width from fifteen miles at Cape Hatteras to about one hundred miles off the southern coast of New England; opposite the Gulf of Maine the southern edge of George's Bank is nearly two hundred miles from the coast of Maine. In the latitude of Cape Cod and nearly south of Cape Sable there is a wide break in the hundred-fathom line, giving access to a tongue of the ocean which, in some places, extends to within fifteen or twenty miles of the coast of Massachusetts and Maine.[1] A similar break, the opening into the Gulf of St. Lawrence, occurs between Sable Island Bank and the Newfoundland banks.

Between Cape Hatteras and the Bahamas there extends a huge triangular plateau, sloping gradually from the shore to about the six-hundred-fathom line, where a steeper slope connects it with the floor of the ocean. As will be seen from the map, the thousand-fathom line runs parallel to the hundred-fathom line from the eastern extremity of George's Bank to Cape Hatteras, and is nowhere more than fifteen miles distant from the former. The slope to the two-thousand-fathom line, however, is by no means so abrupt, except a little south of Hatteras, where it is only about fifteen miles distant. It varies from forty miles off the extremity of George's Bank to over a hundred miles in the normal to the Jersey coast.

On the southern New England coast the continental shelf

[1] Another break in the coast line is thus described by Professor J. E. Hilgard: "During the summer of 1882 the 'Blake,' under command of Lieutenant-Commander W. H. Brownson, was engaged in sounding off the entrance of New York harbor. The charts have hitherto shown a spot about a hundred miles south-east of Sandy Hook known as the 'hundred and forty-five fathom hole.' [Mr. Lindenkohl (American Journal of Science, June, 1885, p. 475) has suggested that this so-called hole is one of a series of mud holes, showing the existence of an ancient river channel, and that these holes were once a part of a deep ravine, forming the outlet of the river to the ocean.] In her soundings, the 'Blake' discovered this hole to have a most remarkable character. Its depth varies from one hundred and fifty to over four hundred and fifty fathoms, the bottom being of mud; and in about the centre a knoll of mud, gravel, and shell rises up to within sixty-four fathoms of the surface. The dividing ridge between the hole at its deepest point and the deep water outside has a least depth of one hundred and twenty-nine fathoms. There seems to be a continuation of bottom of irregular character, which extends from Sandy Hook about south-east; for about two hundred miles farther the depth is over three thousand fathoms, surrounded by very much shoaler depths."

slopes very gradually seaward, forming a broad, slightly inclined submarine plateau. The edge of the plateau beyond the hundred-fathom line falls rapidly to the thousand-fathom line, forming a steep slope, the Gulf Stream Slope, so named by the Fish Commission, because it extends under the inner edge of the Gulf Stream along our coast, from Cape Hatteras to Nova Scotia.

South of Hatteras the hundred-fathom line runs parallel to the coast at a distance of about sixty miles till off Jacksonville. From this point it gradually closes up towards the Florida shore, and is not more than ten miles distant from Jupiter Inlet. It then makes a gigantic sweep and runs parallel to the general trend of the Florida reefs, until it turns abruptly northward about a hundred miles to the westward of the Tortugas. South of Hatteras the thousand-fathom line does not follow the line of the hundred-fathom curve; it extends almost in a straight line from the Cape to the northern extremity of the Bahamas, and is connected with the sloping Carolina-Florida plateau (the "Blake Plateau") by a sharp slope, reaching, however, only about to the six-hundred-fathom line, which in some parts of the plateau off Florida and Georgia is over two hundred miles from the coast line. The two-thousand-fathom line is about ten miles distant from the thousand-fathom line all the way from north of Cape Cañaveral to Sombrero Island, and along the greater part of the east face of the plateau of the Windward West India Islands.

North of Cape Cañaveral as far as Cape Hatteras, the two-thousand-fathom line is from twenty to sixty miles distant from the thousand-fathom line, which forms as it were the bottom of the steep slope of the continental shelf. From this line to the deepest water between the Bermudas and the Atlantic States the slope is hardly perceptible, — a general fall of say twelve thousand feet in a distance of over two hundred and fifty miles, or a slope of about fifty feet to the mile.

The eastern slope of the great Bahama Bank is very much steeper than that of the Atlantic Coast of the United States. In no case is the two-thousand-fathom line more than fourteen miles from land, and in one case Lieutenant-Commander Brown-

son found nineteen hundred and seventy-six fathoms only two and a half miles from land, — a declivity of thirty-eight degrees. The thousand, two-thousand, and twenty-five-hundred fathom lines run parallel to the general line of the eastern row of islands which form the Bahama Bank, from Navidad Bank to Great Abaco Island. Between Navidad Bank and San Domingo, a deep and narrow tongue of the ocean, averaging over two thousand fathoms in depth, extends to opposite the centre of the Windward Passage. The same steep slope is continued north of San Domingo, Porto Rico, the Virgin Islands, along the eastern edge of the Windward Islands, till about off St. Lucia, where the slope is somewhat less abrupt. The thousand-fathom line follows closely the trend of the Windward Islands; but the two-thousand-fathom line begins to diverge off Anguilla and St. Barthelemy, and by running at a considerable distance outside of the Barbados forms a gentler slope than to the north. From off the Caicos Islands the slope is still steeper, a depth of nearly three thousand fathoms being found from there to the Virgin Islands, at a distance of generally less than fifty miles, and often within twenty miles of the hundred-fathom line. The greatest depth reached by the "Blake" has been found off Porto Rico. Lieutenant-Commander Brownson sounded there in four thousand five hundred and sixty-one fathoms,[1] the deepest sounding but one yet made, and traced the extension of the deep water which fills the basin of the Western Atlantic to the west of the Bermudas, and is separated from the deep basin of the tropical Atlantic by a spur of the Dolphin Rise, to the north of St. Paul's Rocks. The temperature, thirty-six and a quarter degrees, clearly indicates that this deep hole, as well as the body of cold water of which it is a part, is also separated by a ridge, which probably rises to a depth of about seventeen hundred fathoms, from the colder water of the South Atlantic; there the temperature is less than freezing, and the water is directly connected with the Antarctic on the eastern part of the South Atlantic. (See Fig. 61.)

[1] Fifteen miles from the deepest point the "Blake" sounded, in four thousand two hundred and twenty-three fathoms, with brown ooze on the top and an under-stratum of gray; temperature, 36° F.

Passing now from the Atlantic to the Caribbean (Fig. 57), we find that a very different topography characterizes the western and eastern parts of this sea. The natural division between them is an immense submarine bank, — the extension of the Honduras and Mosquito coast plateau (which is less than a hundred fathoms) towards Jamaica, — this plateau being, as far as is known, nowhere at greater depth than five hundred fathoms, and forming a number of smaller banks, such as the Rosalind, the Pedro, Serranilla banks, which are less than a hundred fathoms in depth. The Mosquito plateau shelves very gently towards the east, and forms an irregular triangular plateau uniting Jamaica at the five-hundred-fathom line with Honduras. The channel between Jamaica and San Domingo slopes gradually to the thousand-fathom line from both sides. The island of Jamaica forms the western extremity of a chain of mountains extending along the southern coast of San Domingo, but with a tongue to the northward of Navassa between it and Formigas Bank and another between Formigas and Jamaica. These banks, with Porto Rico and the Virgin Islands, constitute the northern boundary of the Eastern Caribbean, and separate it from the Atlantic, leaving only the comparatively shallow Mona Passage with two hundred and sixty fathoms at its greatest depth between San Domingo and Porto Rico, and the still shallower passages running between the Virgin Islands across the plateau, which unites them all and is formed by the hundred-fathom line.

There is a comparatively deep cañon of about eleven hundred fathoms, leading from Sombrero into a small basin of twenty-four hundred fathoms in depth between Santa Cruz and St. Thomas. This cañon, separating the Lesser from the Greater Antilles, has a bottom temperature of thirty-eight degrees, plainly showing that it connects with the Atlantic, and indicating the existence of a ridge running between Santa Cruz and Porto Rico. The "Albatross" (as reported by Commander Bartlett) discovered this ridge, with nine hundred fathoms as its greatest depth. The soundings of the "Albatross" further developed the presence of an elevation running north and south nearly parallel with the chain of the Windward Islands, reach-

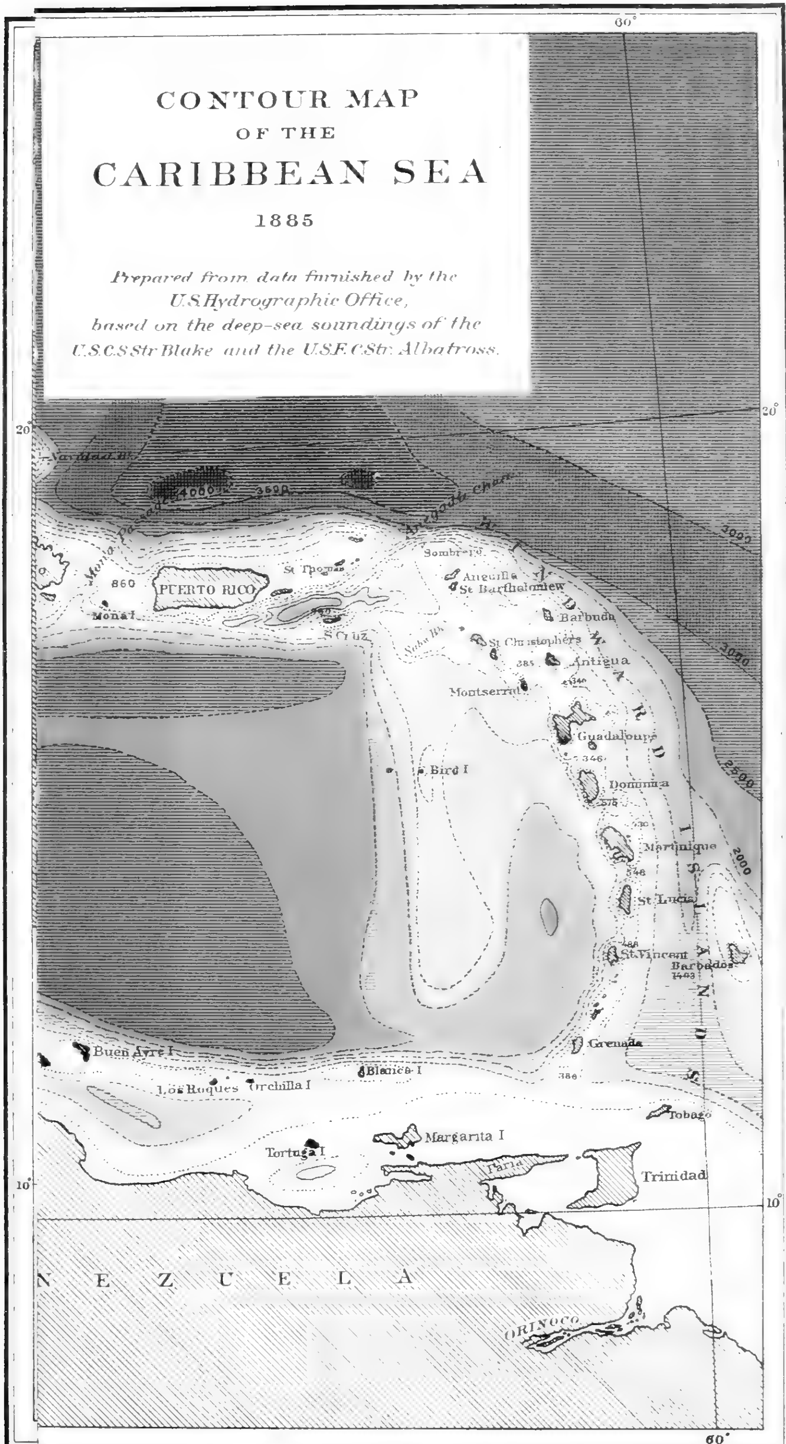
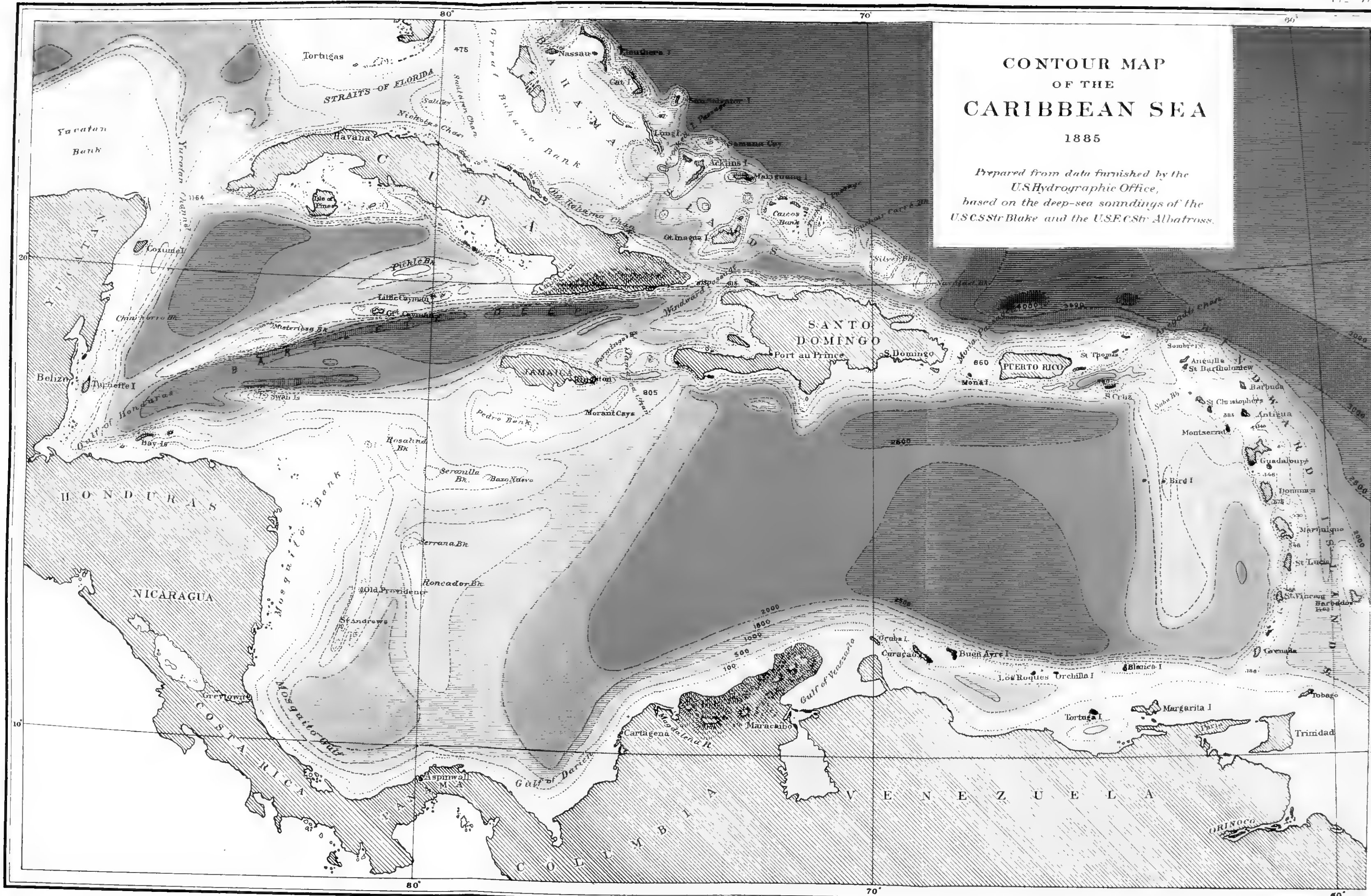

CONTOUR MAP
OF THE
CARIBBEAN SEA
1885
Prepared from data furnished by the
U.S. Hydrographic Office,
based on the deep-sea soundings of the
U.S.C.S. Str. Blake and the U.S.F.C. Str. Albatross.
60°
20°
10°
Navidad Bk
Mona Passage
4000
3500
Anegada Chan
3000
2500
2000
860
PUERTO RICO
Mona I.
St Thomas
S. Cruz
Sombrero
Anguilla
St Bartholomew
Barbuda
Saba Bk
St Christophers
Antigua
Montserrat
Guadaloupe
346
Bird I
Dominica
Martinique
St Lucia
St Vincent
Barbados
Grenada
Buen Ayre I
Los Roques
Orchilla I
Blanca I
Tobago
Margarita I
Tortuga I
Paria
Trinidad
N E Z U E L A
ORINOCO

Fig. 57



B. Meisel, lith.

ing from St. Christopher to Bird Island and about to the latitude of the Grenadines, showing considerably less than a thousand fathoms, with fifteen hundred to two thousand fathoms on each side.

The eastern boundary of the Eastern Caribbean is formed by the dumb-bell shaped plateau, from which rise the Windward Islands. (Fig. 58.) These extend in a gigantic arc from Sombrero and Santa Cruz to Grenada, Tobago, and Trinidad, leaving broad, shallow passages between the islands to the north of Dominica, with the three comparatively deeper straits separating Dominica, Martinique, St. Lucia, St. Vincent. We next come to the still shallower passages over the Grenadines Bank, and the deeper passage between that bank and Tobago. This island, as well as Trinidad, and all the Leeward Islands to the north of Venezuela, lie within the hundred-fathom line.[1] They are all only outposts of the South American continent. From the Gulf of Venezuela to the mouth of the Orinoco the hundred-fathom line is about ninety to one hundred and twenty miles from the South American coast.

The thousand-fathom line, which extends diagonally across the Eastern Caribbean from the south-western extremity of San Domingo to a point about one hundred miles north-west of Aspinwall, runs towards the Venezuelan coast, and follows the line of the hundred-fathom curve, with the exception of an indentation from the deep water, extending to the southward and eastward, between Curaçoa and the mainland. It also follows closely the general trend of the south coast of San Domingo, Porto Rico, and bears to the west of the Windward Islands, being nowhere more than about forty miles from the coast-line, and usually from ten to fifteen miles on the lee side of the Windward Islands to the south of Guadeloupe.

Little is yet known of the depth of the main basin of the Eastern Caribbean; but from the absence of islands and banks, it is probable that it is, like the Gulf of Mexico, a huge oval

[1] The "Albatross," in 1884, ran a line from Curaçoa to the mainland in a southerly direction, the greatest depth found being 738 fathoms at a distance ranging from ten to forty miles. "Albatross," Hydrographic Report, 1884, J. R. Bartlett.

basin, in the north-eastern parts of which a depth of over 2,500 fathoms has been obtained. The only line yet run directly across the main basin of the Eastern Caribbean has been sounded by the "Albatross" from Curaçoa to Alta Vela, a small island on the south coast of San Domingo. The deepest water found was 2,694 fathoms, — the average depth nearer the South American side of the basin being about 2,300 fathoms until within a short distance of the land.

The topography of the Western Caribbean is strikingly different from that of the eastern basin. The soundings of Commander Bartlett have developed an immense submarine valley, extending nearly due east for about seven hundred miles, from the southern extremity of Cuba towards the Chinchorro Bank, off the coast of Honduras. This valley has an average breadth of about eighty miles, and an average depth of over two thousand fathoms. Towards its eastern extremity it attains the depth of nearly 3,200 fathoms, and its greatest depth is 3,428 fathoms twenty miles south of Grand Cayman. So that the highest peaks of the chain of mountains skirting the southern shore of Cuba, which rise to 8,400 feet, are really 28,000 feet above the bottom of this great submarine valley, distant only fifty miles in a straight line. As Commander Bartlett has said, the little Cayman, Grand Cayman, and Misteriosa banks are the summits, just appearing above tide-mark, of a submarine range of an average height of nearly twenty thousand feet. This deep valley, which has most appropriately been called "Bartlett Deep," forms a loop to the eastward of Cozumel Island, south of Pine Island towards the Pickle Bank. Towards the Yucatan Channel, which connects the Western Caribbean with the Gulf of Mexico, the bottom shelves gradually, rising to a height of 1,164 fathoms, — the deepest part of the channel between Yucatan and Cape San Antonio. The Western Caribbean connects with the deep tongue of the Atlantic, reaching north of San Domingo through the Windward Passage, the deepest part of which is 873 fathoms.

We could have no better example than the Gulf of Mexico affords of the deceptive character of the shore-line for obtaining a correct idea of a hydrographic basin. (Fig. 59.) This is

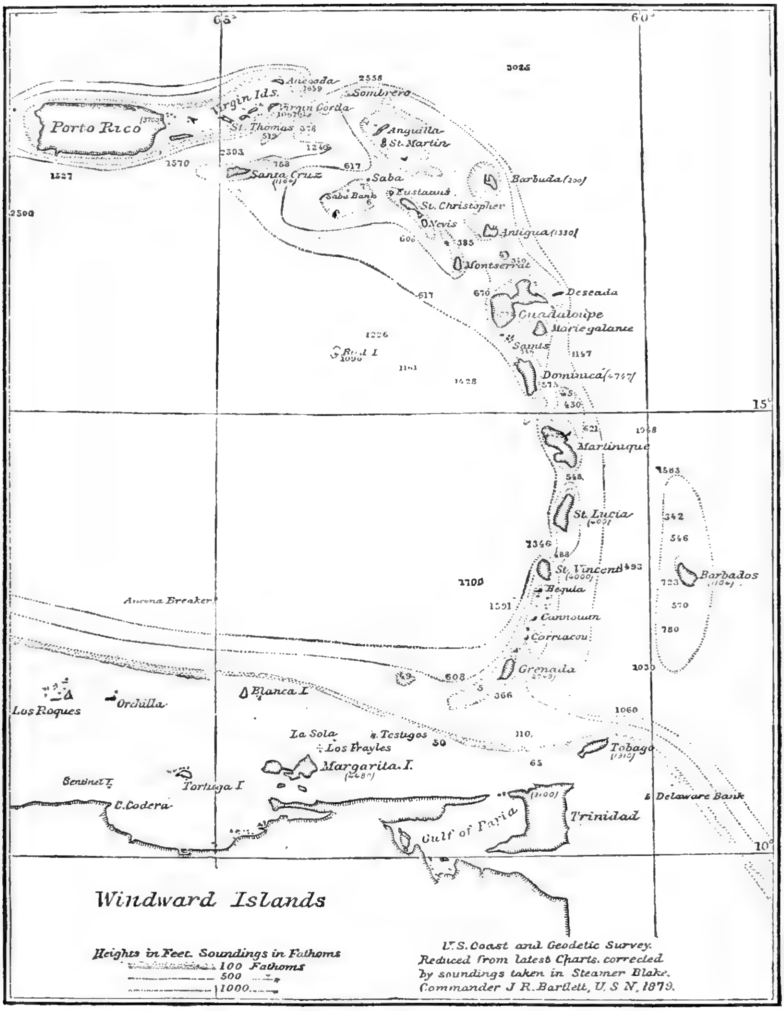


Fig. 58. — SKETCH MAP OF THE WINDWARD ISLANDS.

admirably shown in the account given by Professor J. E. Hilgard, the Superintendent of the United States Coast Survey, at a meeting of the National Academy of Sciences: —

"We perceive that the basin of the Gulf of Mexico is an oval connected with the general ocean circulation by two outlets, the Yucatan Channel and the Florida Straits. The area of the entire Gulf, cutting off by a line from Cape Florida to Havana, is 595,000 square miles. Supposing the depth of the Gulf to be reduced by one hundred fathoms, a surface would be laid bare amounting to 208,000 square miles, or rather more than one third of the whole area. The distance of the hundred-fathom line from the coast is about six miles near Cape Florida; one hundred and twenty miles along the west coast of Florida; at the South Pass of the Mississippi it is only ten miles; opposite the Louisiana and Texas boundary it increases to one hundred and thirty miles; at Vera Cruz it is fifteen miles, and the Yucatan Bank has about the same width as the Florida Bank.

"The following table shows the areas covered by the trough of the Gulf to the depths stated: —

Depth.	Area.	Difference.
2,000 fathoms.	55,000 square miles.	132,000
1,500 "	187,000 " "	73,000
1,000 "	260,000 " "	66,000
500 "	326,000 " "	61,000
100 "	387,000 " "	208,000
Coast line	595,000 " "	

"This table shows that the greatest slopes occur between the depths of one hundred and fifteen hundred fathoms. The maximum depth reached is at the foot of the Yucatan Bank, — 2,119 fathoms. From the fifteen-hundred-fathom line on the northern side of the Gulf to the deepest water close to Yucatan Bank, — say to the depth of two thousand fathoms, — the distance is two hundred miles, which gives a slope of five-ninths to two hundred, and may be considered practically as a plane surface. The large submarine plateau below the depth of twelve thousand feet has received the name of the 'Sigsbee Deep,' in honor of its discoverer.

"The Yucatan Channel, with a greatest depth of 1,164 fathoms, has a cross-section of one hundred and ten square miles, while the Strait of Florida, in its shallowest part opposite Jupiter Inlet, with a depth of 344 fathoms, has a cross-section of only eleven square miles.

"A view of the maps reveals at once some important facts, which were unsuspected before this great exploration was completed. Thus, the distance between the visible coast-lines of the north-eastern point

of Yucatan and the west coast of the Florida peninsula is four hundred and sixty miles, while the distance between the submerged contours of five hundred fathoms is only one hundred and ninety miles; between the contours of one thousand fathoms only ninety miles. These facts at once characterize the Gulf of Mexico as a Mediterranean Sea.

"The most striking features displayed by the map are: —

"The great distance to which the general slope of the continent extends below the present sea-level before steeper slopes are reached. The hundred-fathom curve represents very closely the general continental line; the massifs of the peninsulas of Florida and Yucatan have more than twice their present apparent width.

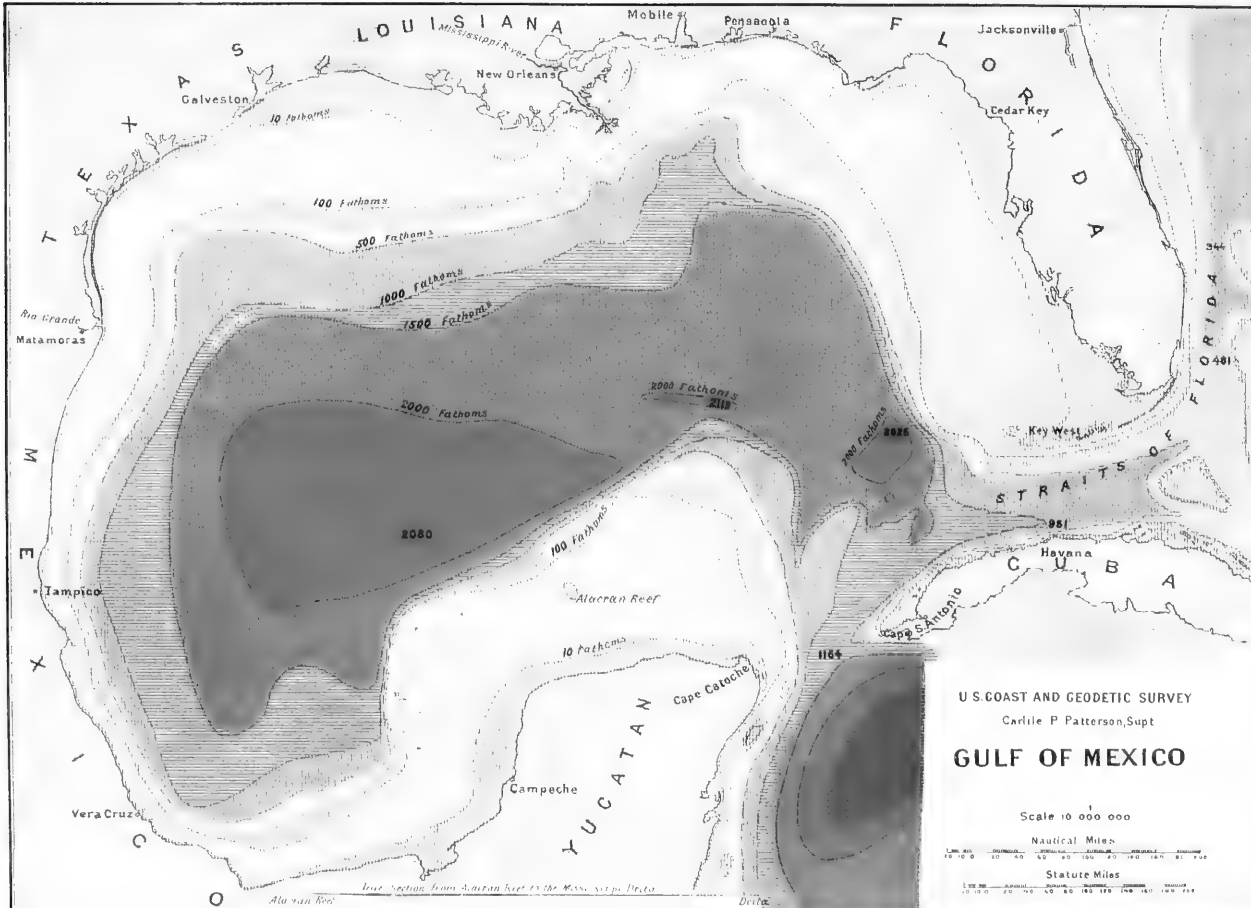
"Very steep slopes lead from this submerged plateau to an area of fifty-five thousand square miles, — as great as that of the State of Georgia, — at the great depth of over twelve thousand feet. There are three ranges on the Florida and Yucatan slopes, extending in the aggregate to more than six hundred miles, along which the descent between five hundred to fifteen hundred fathoms, or six thousand feet, is within a breadth of from six to fifteen miles. No such steep slopes and correspondingly elevated plateaux appear to exist on the unsubmerged surface of the earth. With the exception of the deep submarine valleys, cañons, and steep slopes found in the proximity of volcanic islands, continental slopes are small, except beyond the continental shelf, as off the Yucatan and Florida plateaux at the Bermudas, Bahamas, and off Hatteras.

"The protrusion of the Mississippi delta toward the deep water of the Gulf seems to give evidence to the engineer of the probably permanent success of the Mississippi jetties, as delivering the silt of the river into water of so great depth, that but few extensions will ever become necessary."

The principal topographical features of the Gulf of Mexico are the great banks which lie within the hundred-fathom line, and occupy no less than one-third of the surface. While the shore line of Texas and Louisiana slopes very gradually towards the deepest part of the Gulf (Sigsbee Deep), the Mexican coastline north of Vera Cruz is somewhat steeper. The west slope of the great Florida Bank as well as the north-west slope of the Yucatan Bank are characterized by their steep inclinations. In two places along the Yucatan Bank the horizontal distance between the hundred-fathom line and the fifteen-hundred-fathom curve is only from fifteen to twenty miles.

If now we attempt to get a general idea of the submarine

Fig. 59.


U.S. COAST AND GEODETIC SURVEY
Carlile P. Patterson, Supt.
GULF OF MEXICO
Scale 1/10 000 000
Nautical Miles
Statute Miles
LOUISIANA
TEXAS
FLORIDA
MEXICO
YUCATAN
CUBA
STRAITS OF FLORIDA
Mobile
Pensacola
Jacksonville
Cedar Key
New Orleans
Mississippi River
Galveston
Rio Grande
Matamoras
Tampico
Vera Cruz
Campeche
Cape Catoche
Alacran Reef
Cape S. Antonio
Havana
Key West
10 fathoms
100 fathoms
500 fathoms
1000 fathoms
1500 fathoms
2000 fathoms
2080
2119
2025
981
1164
344
481

landscape of the districts we have described, we cannot fail to observe how strikingly it differs from terrestrial landscapes. They present no proper parallel to the immense stretches of hundreds of miles of gently sloping surfaces, such as form the deepest part of the basin of the Gulf of Mexico, and of the Eastern Caribbean, and the similar expanse of bottom which extends along the whole Atlantic coast of the United States. Aerial denudation is so powerful a factor that the least difference in the hardness of the material of adjoining tracts is

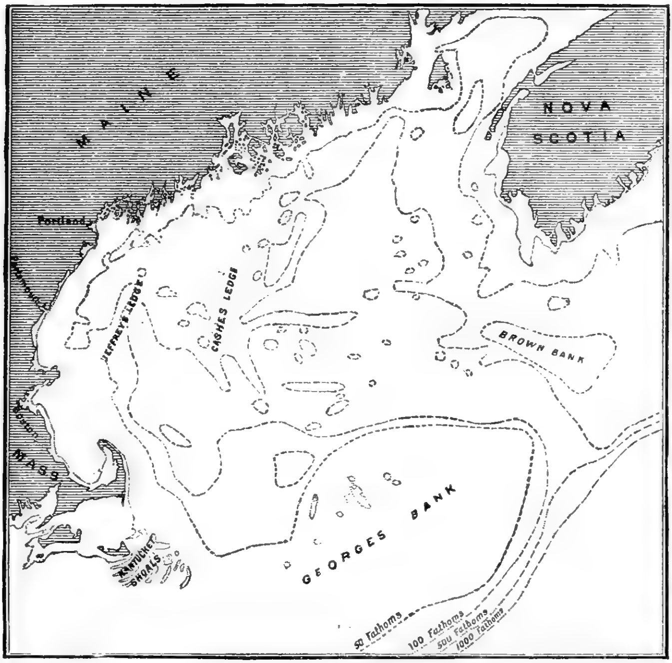


Fig. 60. —Gulf of Maine.

sufficient to effect very striking changes in level. These find their ultimate expression, in connection with the geological structure, in such characteristic regions as the cañons of the far West, the Mauvaises Terres, the summits of the Rocky Mountains and of the Sierra Nevada, the Appalachian system, the prairies of the West and the system of the Great Lakes, the hydrographic basins of the Mississippi and of the St. Lawrence.

The effect of strong currents and tides, at moderate depths, is well shown in the topography of the Gulf of Maine, as mapped on the Coast Survey charts. (Fig. 60.) Here the tides are high, the currents powerful, and the effect on the bottom in producing ledges, banks, etc., is in striking contrast to the bottom in the tideless sea of the Gulf of Mexico. But no influence of this kind is at work at a great depth in the ocean. The action of currents is probably not limited by depth, as we see in the exceptional case of the Gulf Stream; but the action of the winds and waves is felt at only very moderate depths; and it is only in volcanic regions, like those of the West Indies and of Japan, that soundings have revealed thus far any striking topographical features. The very absence of modifying and disturbing conditions, such as chemical and aerial denudation, tends to keep the original features due to submarine disturbances of the earth's crust more or less intact; and it is to the absence of those conditions that we undoubtedly owe the existence of such gigantic plateaux as the Yucatan Bank, and the great Florida Bank, with its eastern extension of the Bahama Bank, which reaches out till it nearly meets the comparatively narrow South American bank, that extends from the mainland to Sombrero.

What can be more impressive than the stupendous slope of over twelve thousand feet that forms the eastern edge of the Bahama Bank, stretching from the Great Abaco nearly unbroken as far as the Virgin Islands, with high passes between Porto Rico and San Domingo, and a deep cañon between San Domingo and the southern end of the Bahama Bank? The northern extremity of this cliff, over seven hundred miles long, forms the edge of a huge triangular plateau, five hundred miles by two hundred and fifty, scarcely rising above the level of the sea, and flanked on its western side by the high chains of Cuba. Its eastern extremity falls into the edge of a sink, of a depth of over four thousand fathoms, and culminates at a horizontal distance of less than eighty miles in a summit on the island of Porto Rico, no less than thirty thousand feet above the lowest point of that depression. What can be more graceful than the comparatively narrow chain of the curve formed by the Windward

Islands, rising from twelve to sixteen thousand feet above the bottom of the Eastern Caribbean, with the many passes between them, — the sieve through which the warm surface water of a great part of the equatorial current is forced by the trade-winds?

We may imagine for a moment that we are taking a bird's-eye view of this whole district, and look down upon the comparatively level plains of the Atlantic to the eastward of the Barbados. These plains rise from a depth of three thousand fathoms to the hundred-fathom line in a distance varying from three hundred and fifty to two hundred miles on the eastward of the Windward Islands; the highest summits of these islands (five thousand feet) are only separated by narrow passages, and thus form a more or less continuous chain of volcanic peaks. On the westward, toward the Caribbean, the slope is more rapid; a depth of one thousand to fifteen hundred fathoms is reached at a comparatively short distance to the leeward of the Lesser Antilles. The chain is narrowest between Martinique and Dominica, widening gradually towards Grenada and Tobago to the south, and somewhat faster towards the Virgin Islands, which are separated from the Santa Cruz, Saba and Sombrero banks by a deep basin opening into a narrow cañon of about one thousand fathoms, with a shallow connecting ridge between Santa Cruz and Porto Rico.

The mountain chain, of which San Domingo, Porto Rico, and the Virgin Islands form the summit, has a steep slope to the north, dropping at the eastern extremity, at a distance of less than one hundred miles, to a depth of three thousand fathoms. The two-thousand-fathom line runs along the eastern edge of the Bahama Bank, a distance of less than fifteen miles, and forms a steep edge to that face of the bank, while the thousand-fathom line cuts off a few isolated outside patches, and extending far to the westward, beyond the Windward Passage, forms the mouth of the funnel of the old Bahama Channel.

The southern slope of this part of the West India Islands chain is fully as steep as the northern. At the western extremity of San Domingo, the southern line of mountains extends toward Jamaica, and that part of the chain is deflected to the

southward, having also a much gentler slope, and forming the edge of the Pedro Rosalind Bank, the extension of the Honduras Mosquito coast, which divides the Caribbean into an eastern and western basin. After passing the Pedro Rosalind Bank, — the divide between the Western and Eastern Caribbean, — one comes into the valley of the Grand Cayman, the eastern extremity of which is flanked on the one side by the Blue Mountains of Jamaica, on the other by the coast range of Southern Cuba, the highest summits of which rise fully twenty-seven thousand feet above the deepest point of "Bartlett Deep," — the extension of the Cuban side of the valley being formed by peaks, often rising to over twenty thousand feet from the bottom of the valley. Compared to such panoramas the finest views of the range of the Alps sink into insignificance; it is only when we can get a view of portions of the Andes from the sea-coast, or such a panorama as one has from Darjiling, facing the Kinchinjinga range, which towers fully twenty-six thousand feet above the level of the valley at its base, that we get anything approximating to it in grandeur.

As it has been the practice with geographers to name the highest peaks of our mountain chains after distinguished explorers, so it has become the custom of hydrographers to name the deepest parts of the oceans after distinguished hydrographers. Sigsbee Deep in the Gulf of Mexico, Bartlett Deep in the Western Caribbean, Thomson Deep and those of Nares, the "Challenger," Pourtalès, Patterson, Hilgard, and others, have been named in connection with recent deep-sea hydrography.

The monotony, dreariness, and desolation of the deeper parts of this submarine scenery can scarcely be realized. The most barren terrestrial districts must seem diversified when compared with the vast expanse of ooze which covers the deeper parts of the ocean, — a monotony only relieved by the fall of the dead carcasses of pelagic animals and plants, which slowly find their way from the surface to the bottom, and supply the principal food for the scanty fauna found living there.

Nearer to the continental masses we find the slopes inhabited by a more abundant and more varied fauna, increasing in

variety and numbers according to the amount of food available. But no matter how varied or how abundant life may be, the general aspect of the slopes must be dreary in the extreme, and can only be compared in character to those higher mountain regions where we find occasional fields of wild-flowers and low shrubs, or to those zones lying beyond the limits of forests, where vegetation is scanty and poor, and forms but a slight covering to the earth's surface.

It is true that along the continental slopes, where there is an ample supply of food, we find animal life in great abundance, and there are undoubtedly long stretches of bottom carpeted by the most brilliantly colored animals, packed quite as closely as they are on banks in shallower waters, or near low-water mark. But the scene is much less varied than on land; the absence of plants in deep water makes great diversity of scenery impossible. The place of luxuriant forests with the accompanying underbrush and their inhabitants is only indifferently supplied by large anthozoa and huge cuttle-fishes, or nearer in shore, within moderate depths, by sea-weed and the pelagic forests of giant kelp.

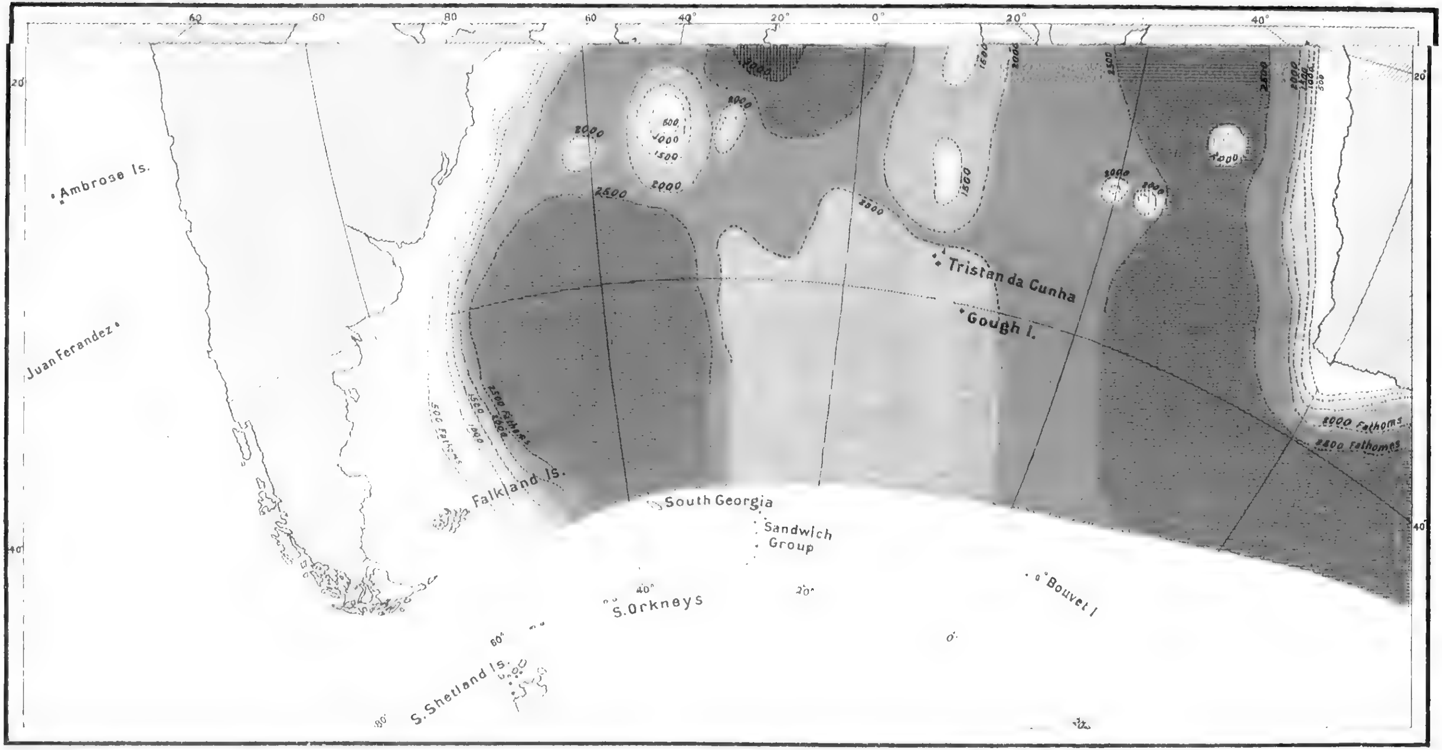
It requires but little imagination to notice the contrasts, as we pass from the shallow littoral regions of the sea, — full of sunlight and movement, and teeming with animal and vegetable life, — into the dimly lighted, but richly populated continental zone; and further to imagine the gradual decrease of the continental fauna, as it fades into the calm, cold, dark, and nearly deserted abyssal regions of the oceanic floors at a distance from the continents. It is like going from the luxuriant vegetation of the tropical shore line — the region of palms, bananas, and mango — into the cooler zone of oaks and pines, until we pass out into the higher levels, with their stunted vegetation and scanty fauna, and finally into the colder climate of the bleak regions of perpetual snow.

The soundings thus far taken by the "Bulldog" and other vessels to ascertain the general topography of the North Atlantic (Fig. 61), the extensive lines of soundings across the North Pacific by the "Tuscarora," the "Challenger," and the "Gazelle," show that the topography of the ocean basins is far less

varied than that of continental areas. As a general rule we find that the continental masses form platforms sinking quite rapidly into the adjoining oceanic basins. The hundred-fathom line may extend far out to sea in some cases, as, for instance, in the northwestern extremity of France, where it unites Great Britain and France. On the east coast of the United States an extensive plateau — the continuation, in other words, of the continent below the surface — follows the hundred-fathom line along our southern coast to the extremity of George's Bank, expanding again farther north, off the coasts of Nova Scotia and of Newfoundland, so as to include Sable Island Bank and the Great Banks of Newfoundland within the true continental line. In the case of the West India Islands, this line discloses a connection between adjoining islands which the mere study of the land map would fail to show. But the hundred-fathom line is simply the edge of the continental plateau along which the detritus brought from the continents by its rivers is deposited. Upon its slope the fauna characteristic of any region extends into deep water, gradually becoming modified in its character by the temperature of the region into which it finds its way. Beyond this hundred-fathom line there is usually a very rapid descent into deep water. This line may indeed be considered as the true continental outline, the edge of the shelf which forms the continuation of the continental masses, below the surface and beyond those shore lines which we are accustomed to consider as the true boundary between land and water.

CONTOUR CHART OF THE BOTTOM OF THE ATLANTIC.

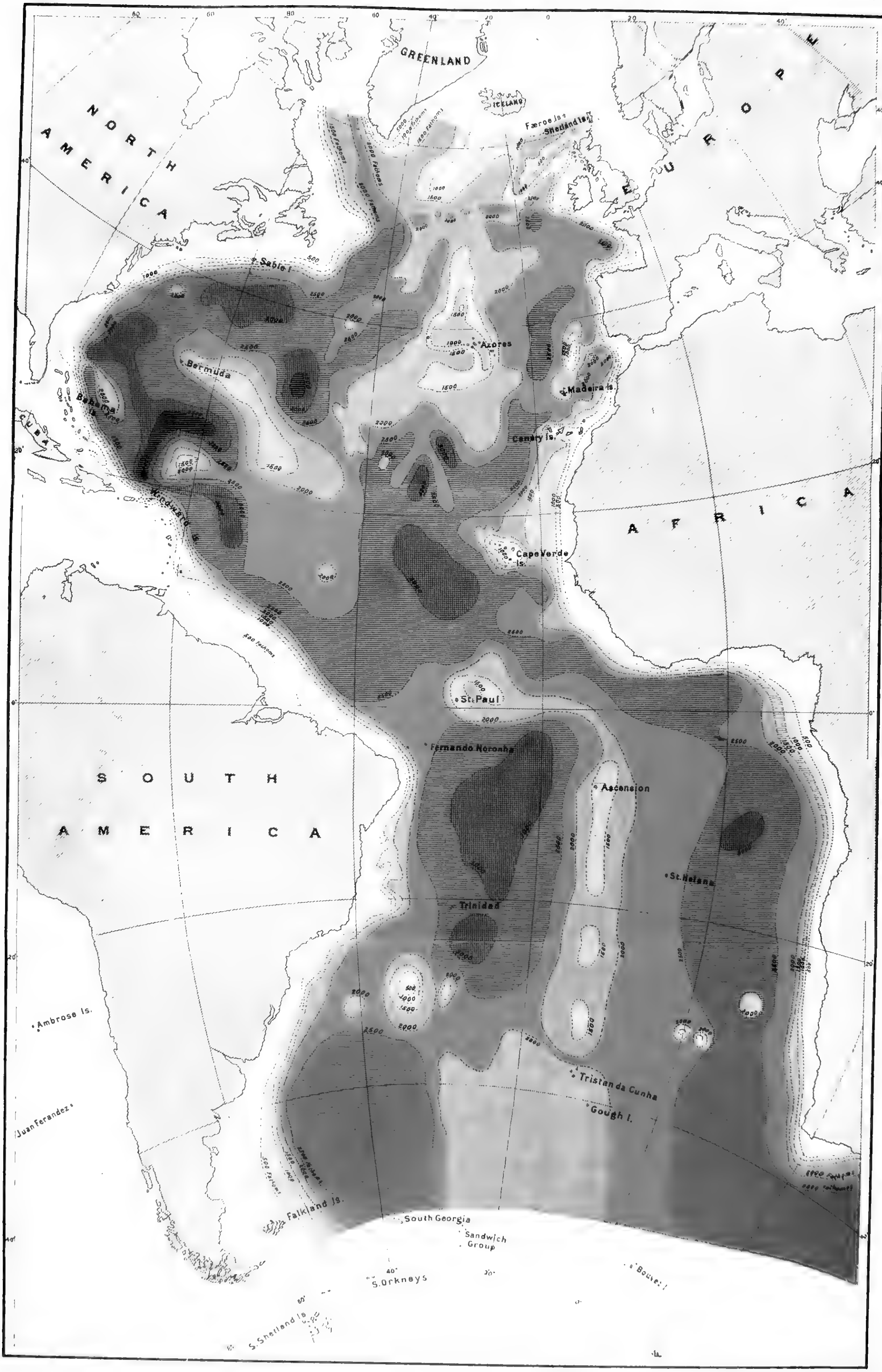
Fig: 61



U. S. HYDROGRAPHIC OFFICE, COMMANDER J. R. BARTLETT, U.S.N. HYDROGRAPHER.

Fig. 61

CONTOUR CHART OF THE BOTTOM OF THE ATLANTIC.



U. S. HYDROGRAPHIC OFFICE. COMMANDER J. R. BARTLETT, U. S. N. HYDROGRAPHER

V.

RELATIONS OF THE AMERICAN AND WEST INDIAN FAUNA AND FLORA.

A GREAT number of animals and plants date back to a time anterior to the present configuration of land and sea. In certain regions we are therefore justified in looking for traces of ancient terrestrial or oceanic connections to explain the presence of identical types at isolated points.[1]

The explorations of the "Blake," though primarily turned toward the investigation of the ocean floor, had an incidental bearing also upon these and similar problems. The work of the "Blake" has added much to our knowledge of the former connection between South America and the West India Islands, and has taught us something also of the agencies which have helped to determine their peculiar fauna and flora. Indeed, hydrographic researches have given us the only acceptable theory of the mode in which many oceanic islands have received their present fauna and flora.

According to Cleve,[2] the oldest fossiliferous rocks of the West Indies belong to the cretaceous, and were probably deposited in a time of powerful volcanic action. Upon the highly disturbed and metamorphosed cretaceous rocks are found almost horizontal and undisturbed miocene beds. The eocene beds are also to a certain extent metamorphosed, while the miocene period must have been a period of long volcanic calm. The position of the most recent pliocene and postpliocene beds seems to indicate that some of the volcanoes now active in the West Indies date back to the pliocene period, others to the postpliocene.

[1] See Wallace's "Geographical Distribution of Animals," and his "Island Life."

[2] Kongl. Svensk. Vetensk. Akad. Handl. Bdt. 9, No. 12. 1871.

The islands to the north of Guadeloupe form two parallel chains, the western consisting of Saba, St. Eustatius, St. Kitts, Nevis, Redonda, and Montserrat, all of which are volcanoes of postpliocene date; while to the eastward is a chain of volcanoes of tertiary age, — Sombrero, Anguilla, St. Martin, St. Barthelemy, Barbuda, and Antigua. At Guadeloupe the recent islands are directly united with the volcanic chain, and the still more modern limestones are found on its western shores.

The miocene rocks of the greater West India Islands[1] have been, as far as observed, but little disturbed. The cretaceous beds, however, are found greatly modified.

The geological history of Florida is in striking contrast with that of the greater and lesser West India Islands. The share which modern limestones have had in building up a portion of the peninsula during the most recent geological period has been described in the chapter on the Florida Reefs. From the observations of Conrad, of E. A. Smith, and of E. Hilgard, it would appear, as is stated by Smith,[2] that up to the end of the eocene, the great Florida limestone plateau was still submerged; that during the time of the upper eocene, Florida was elevated nearly to its present height. The axis of elevation did not coincide with the present dividing ridge of the peninsula, but occupied probably a position to the westward. From the subsequent deposition of sand, clay, and pebbles over Florida and parts of the adjacent States, they must have been slightly submerged again, and subsequently elevated (during the Champlain period) to about their present configuration.

In attempting to reconstruct, from the soundings,[3] the state

[1] The most striking feature of the West India Islands as a whole is the axis of eruptive rocks, flanked by sedimentary formations and terraces of elevated coral reefs and recent limestones. On the northern coast of Cuba the mode of formation of the harbors within the fringing reef, inside of the great outside barrier reef, seems to prove that the rivers cut their way out as fast as the land was elevated and the successive terraces formed. It must be remembered that coral reefs have no such thickness as is seen on the terraces, but that the greater part of this limestone was probably deposited much as was the limestone that forms the backbone of the Yucatan and Florida peninsulas. This limestone was subsequently capped by reef-building corals during periods of rest, followed by the elevations to which the successive terraces are due.

[2] Smith, E. A. American Journal of Science, April, 1881, p. 292.

[3] See the accompanying maps (Figs. 57, 58), for which I am indebted to the Hon. Carlile P. Patterson, Superintendent U. S. Coast Survey.

of things existing along the Lesser and Greater Antilles in a former period, we are at once struck by the fact that the Virgin Islands are the outcropping of an extensive bank. The greatest depth between these islands is less than forty fathoms, a depth which is found on the bank to the east of Porto Rico, — the hundred-fathom line forming, in fact, the outline of a large island, which would include the whole of the Virgin Islands, the whole of Porto Rico, and extend some way into the Mona Passage. The hundred-fathom line similarly forms a large plateau, uniting Anguilla, St. Martin, and St. Barthelemy. It also unites, as separate banks, Barbuda and Antigua, forms the Saba Bank, and unites St. Eustatius, St. Christopher, and Nevis. It unites Redonda with Montserrat. It forms an elongated plateau, from Bequia to the southwest of Grenada, and runs more or less parallel to the South American coast from Margarita Island, leaving a comparatively narrow channel between it and the hundred-fathom line south of Grenada, so as to enclose Trinidad and Tobago within its limits, and runs off to the southeast in a direction also about parallel to the shore line. At the western end of the Caribbean Sea the hundred-fathom line forms a gigantic bank off the Mosquito coast, extending over one third the distance from the mainland to the island of Jamaica. The Rosalind, Pedro, and a few other smaller banks, limited by the same line, denote the position of more or less important islands which may have once existed between the Mosquito coast and Jamaica. On examining the five-hundred-fathom line, we thus find that Jamaica is only the northern spit of a gigantic promontory, which perhaps once stretched toward Hayti from the mainland, reaching from Costa Rica to the northern part of the Mosquito coast. There is left but a comparatively narrow passage between this promontory and the five-hundred-fathom line which encircles Hayti, Porto Rico, and the Virgin Islands, in one gigantic island.

The passage between Cuba and Jamaica has a depth of over three thousand fathoms, and that between Hayti and Cuba is not less than eight hundred and seventy-three fathoms in depth. The five-hundred-fathom line connects the bank uniting Anguilla to St. Barthelemy, the Saba Bank, the one which joins

St. Eustatius to Nevis, and Barbuda to Antigua, and thence extends south so as to include Guadeloupe, Marie-Galante, and Dominica.[1] The five-hundred-fathom line thus forms one bank of the northern islands, and leaves but a narrow channel between it and the eastern end of the five-hundred-fathom line running round Santa Cruz. Santa Cruz is separated from St. Thomas by a channel of forty miles, which thus forms a basin with a maximum depth of over twenty-four hundred fathoms. It is united with Porto Rico by a submarine ridge with a depth of about nine hundred fathoms. This plainly shows its connection with the northern islands of the Caribbean group, rather than with St. Thomas; yet, as is also well shown by the geographical relations of its mollusca, their affinities are rather with Porto Rico and that group of islands than with the Caribbean Islands. This may be explained by the existence of an easterly current setting along the shore, or of a former land connection with Porto Rico, still indicated by a ridge discovered by the "Albatross," running from Santa Cruz to Porto Rico, having a maximum depth of nine hundred fathoms. The five-hundred-fathom line again unites, in one huge spit extending northerly from the mouth of the Orinoco, all the islands to the south of Martinique, leaving Barbados to the east, and a narrow passage between Martinique and the islands of Dominica and St. Lucia.

At the time of this connection, if it existed, the Caribbean Sea was connected with the Atlantic only by a narrow passage of a few miles in width between St. Lucia and Martinique, by one somewhat wider and slightly deeper between Martinique and Dominica, by another between Sombrero and the Virgin Islands, and by a comparatively narrow passage between Jamaica and Hayti. The hundred-fathom line connects the Bahamas with the north-eastern end of Cuba; the five-hundred-fathom line unites them not only with Cuba, but also with Florida. The Caribbean Sea, therefore, must have been a gulf of the Pacific, or have been connected with it by wide passages, of which we find the traces in the tertiary and cretaceous deposits

[1] Between Martinique and Dominica a peak in mid-channel was found within eighty-five fathoms of the surface.

of the Isthmus of Darien, of Panama, and of Nicaragua. Central America and northern South America at that time must have been a series of large islands, with passages leading between them from the Pacific into the Caribbean.[1]

It is further interesting to speculate on what must have become of the equatorial current, or rather of the current produced by the northeast trades. The water banking up against the two large islands, then forming the Caribbean Islands, must, of course, have been deflected north, have swept round the northern shores of the Virgin Islands, Porto Rico, and Hayti, and poured into the western basin of the Caribbean Sea, through the passage between Hayti and Cuba. This water was forced into a sort of funnel, by the five-hundred-fathom line, which constituted the southern line of the great Bahama Island, and connected nearly the whole of the Bahamas with Cuba, forming thus a barrier to the western flow of the equatorial current; this current must, therefore, for the greater part, have been deflected north, and either swept in a northeasterly direction, as the Gulf Stream now does, or round the north end of the Bahamas across Florida, which did not then exist, across the Gulf of Mexico, and into the Pacific over the Isthmus of Tehuantepec.

While undoubtedly the soundings indicate clearly the nature of the submarine topography, it by no means follows that this ancient land connection did exist as has been sketched above. At the time when the larger West India Islands were formed and elevated above the level of the sea, they may have been raised as one gigantic submarine plateau of irregular shape, in which were included the Bahamas, Florida, Cuba, San Domingo, Porto Rico, and the Virgin Islands. Exactly what portions rose above the level of the sea at that time it is difficult to determine, and it may be that at that period the islands, while larger perhaps than they are now, may still have been the same in number, having since been reduced in size by denudation, while the channels between them have been widened.

[1] We should bear in mind that the Windward Islands were probably raised long after the range of the greater West India Islands existed, thus leaving a free access to the Pacific up to that time.

As is well known, Cuba, the Bahamas, Hayti, and Porto Rico, instead of having, as we might naturally assume from their proximity to Florida, a decided affinity in their fauna and flora with that of the southern United States, show, on the contrary, unmistakable association with that of Mexico, Honduras, and Central America; the Caribbean Islands indicate in part the same relationship, though the affinity to the Venezuelan and Brazilian fauna and flora is much more marked. The most characteristic feature of the West Indian fauna is the immense development of the land mollusks; the birds are South American; and terrestrial mammals are almost wanting, with the exception of three genera peculiar to the larger islands.

One of the most remarkable of the mammalian types of the greater West India Islands is the insectivore Solenodon,[1] belonging to a family of which representatives are known only from Madagascar. The rodents are all members of groups characteristic of South America. The agouti, which once extended to the large islands, is now said to be found mainly in the Windward Islands.[2] The islands of Trinidad, Tobago, and the Leeward Islands, are all on the great continental plateau of South America, detached parts of the mainland itself, and have its characteristic fauna and flora.

In view of the short distances between the West India Islands it is not astonishing that the birds should partake somewhat of the character of North, Central, and South America. There are a number of North American birds which spend the winter on these islands, or migrate farther south. The fact that the majority of them only visit Cuba and Jamaica may be explained by the direction of the tradewinds, which would prevent them from reaching Hayti, Porto Rico, or the more eastern Windward Islands. Many of the birds formerly found in some of the smaller islands have become exterminated by the increase of population and the clearing of the forests. It is most probable that in these islands, so favored in their climate and their flora,

[1] But as the insectivores are now dying out, we may consider this genus a remnant of a group formerly having a much wider distribution.

[2] In the caves of Anguilla are found fossil mammals belonging to South American types.

special conditions more or less favorable to certain genera would be produced, and thus tend to the remarkable specialization of many of the birds in individual islands. This, as suggested by Wallace, would show that the islands were not peopled by immigration from surrounding countries while in the condition we now see them.

The reptiles show likewise a general relation to the Central American and Mexican types. One of the most interesting is a gigantic land tortoise, found at Porto Rico, differing only in size from the land turtle still found on Trinidad and adjoining parts of South America. It is closely allied to the gigantic turtles of the Galapagos and Mascarene Islands, and to the fossil land turtles, of which fragments have been described by the late Professor Wyman. These were collected by Mr. A. A. Julien at Sombrero, in the phosphate beds of the island.

The species of iguana characteristic of the small island of Navassa and of Hayti presents a case of specialization very similar to that of the Amblyrhynchus of the Galapagos, and of an allied species occurring at the Fiji Islands. The aquatic habits of these large saurians make a migration to a distant point quite feasible.

It is from the study of the land shells, however, which have been so carefully observed by Bland and others, that we may get a better idea of the great specialization which has taken place in the development of the molluscan fauna characteristic of the different islands. If, as we may assume, the islands have received their molluscan fauna from the adjoining mainland, we might naturally expect that those islands which were more recently connected with the mainland, or to which access, owing to the direction of the winds and currents, was most easy, would show a greater preponderance of continental forms than those which have been longer separated from the main coast, or to which the winds and currents do not lead so directly. In addition, the more or less favorable physical features of the different islands have undeniably had their influence in the increase of the land shells.

The greater West India Islands, according to Bland, are nearly equally rich in land shells. The eastern islands, Porto Rico and

the Virgin Islands, are somewhat poorer, and as we come to the Windward Islands the West Indian types disappear and are replaced by continental forms. In the Bahamas we find no continental types, the species being most clearly allied to those of Cuba, with which geologically and physically they are in closer connection.

While the flora of Florida undoubtedly has many of the characteristic features of that of the Southern States, it has also a decided West Indian tinge. Its mangroves, limes, and palmettos connect it with the vegetation found on the other side of the Straits of Florida, and along its southern extremity are found West Indian, Mexican, and Central American birds, which rarely find their way farther north than the Everglades.

Our imperfect knowledge of the geology of Central America tends to show that South America must have remained isolated from North America before the tertiary period; that during palæozoic times it formed a huge archipelago, and that its connection with North America was never a very close one. Hence the migration during tertiary times of many of the American forms has produced in the West Indies and the Central American districts a strange mixture of ancient and recent types. Many of these are now extinct both in North and South America. This want of close connection between the Americas has probably affected the fauna of South America much as it has that of the West Indies, and produced conditions highly favorable to the extraordinary development of specific forms, which characterizes the fauna of tropical America beyond all other faunal districts.

The deep soundings (over three thousand fathoms) developed by the "Blake" south of Cuba, between that island and Yucatan and Jamaica, do not lend much support to the theory of an Antillean continent as mapped out by Wallace, nor is it probable that this continent had a much greater extension in former times than now, judging from the depths found on both sides of the West India Islands. This would all tend to prove the want of close connection between the West India Islands and the adjoining continent. It leads us to look, for the origin of the fauna and flora of those islands, to causes similar to those which

have acted upon oceanic islands. The proximity of these islands to a great continent has, however, intensified the efficiency of these causes.

Among the oceanic islands which show most clearly the effects of ocean currents and of winds on the distribution both of marine and of terrestrial animals and plants, the Bermudas are the most interesting. Situated in the very track of the Gulf Stream, we readily trace to their origin a host of littoral marine animals and many plants, known to us from the investigations of the older naturalists, in the West Indies and the northern shores of South America; while the more recent investigations have shown the community of origin of a number of rarer Bermudan types with forms found in the deeper waters of the Caribbean Sea, the young of which are carried northward during their pelagic embryonic stages, with the seeds of many of the plants which have become acclimated in the Bermudas.

The fact that the Bermudas are of comparatively recent origin shows how varied the fauna and flora of a group may become when placed in the path of a current or of prevailing winds, and how comparatively little time is required for the acquisition of faunistic characters which may closely link the group to distant shores. Were the conditions of winds and currents changed, we might be tempted to explain these characters upon the theory of former land connections, which perhaps never existed.

The vegetation of the Bermudas is thoroughly Floridian and West Indian, consisting of palmettos, mangroves, junipers, limes, etc.; and we can easily see how the seeds or shoots of many plants can have been brought by the Gulf Stream and settled on the low shores of the islands when they once rose above the level of the sea. There are no mammals except the rats and mice imported with vessels. The birds are not numerous; they are common North American species, of which only a few breed on the island, while there are other annual visitants. The only land reptile known there is closely allied to, if not identical with, a species of skink inhabiting the Carolinas, and the marine fauna and flora are West Indian. The large turtles of the coast of Florida, the fishes, mollusks, crustacea, polyps, and

echinoderms, all indicate the source from which they have been derived.

It is interesting in connection with the currents to note that, as far as we know, the Bermudas were never inhabited by Caribs or North American Indians, their great distance from land and the facility with which boats, carried northward by the Gulf Stream, must have drifted towards the mainland rendering such an immigration quite improbable.

In this special case it is not difficult to go back to the time (and that in a comparatively recent geological period) when the Gulf Stream did not run its present course, and when probably also the Bermudas, if they existed at all, were merely the nucleus on which the subsequently formed atoll has been raised. We may safely assert that their existence as a coral reef dates from the time of the closing of the passages through which the equatorial currents flowed across the Isthmus of Tehuantepec and the other passes of the Isthmus of Panama. The coral reef of the Bermudas is probably, therefore, of very much more recent origin than the reefs on the windward sides of the West India Islands, the southern coast of Cuba, the Mosquito coast, the Yucatan Bank, the north shore of Cuba, the Florida reefs, and the Bahamas and their connecting islands. It is to these older reefs that the more recent Bermuda reefs owe their origin. The embryos of the corals were floated northward by the Gulf Stream, and finding suitable conditions of temperature, as well as of depth, due to this very current, became attached, and soon formed a gigantic atoll rivalling in size some of the more prominent atolls of the Pacific. Thus we readily account for the presence of coral reefs off the Atlantic coast of North America, in latitudes which are rather more northerly than the usual extension of coral reefs in other seas. The same causes which have thus scattered as far north as the Bermudas the fauna and flora of the West Indies, and of some parts of tropical South America, have also been influential in extending some of these types to their more distant habitats, such as the Azores, the Canary Islands, Cape Verde Islands, Madeira, the west coast of tropical Africa, as well as to other points on the east coast of North America, where a few of the same animals and plants occur.

On the Atlantic shores of the United States we have on a more extended scale a repetition of the phenomenon first observed in the Færöe Channel by the "Lightning," of the difference produced on the character of the fauna by a change of temperature. The "warm and the cold areas," as they have been termed there, find their parallel on our coast as seen in the extension of the West Indian fauna along the line of the continental slope bathed by the Gulf Stream, flanked on either side by the arctic fauna living in the colder water of the bottom of the Gulf Stream on the east, and in the cold arctic waters which bathe the continental plateau within the sixty-fathom line on the western edge of the area occupied by this more tropical fauna. This shows in a remarkable way the powerful influence exerted by the action of the heated water of the Gulf Stream in extending to the northward, along the bottom, the range of the fauna of a more southern latitude. This action is not limited to the bottom, for on the surface also the characteristic pelagic fauna is carried northward. The larvæ of many of the Caribbean and Mexican animals which swim, find an abode as far north as the conditions of the water and the bottom will allow; the adults may also, little by little, creep up northwards.

This northern extension of the southern fauna has been carefully studied by the United States Fish Commission along the southern coast of New England; their dredgings have proved the existence in this region of many animals known before only from Florida, and of others which were previously considered as characteristic tropical types. In fact, we have a northern extension, off the southern coast of New England, of the West Indian and Gulf Stream fauna. The warm belt extending from sixty-five to one hundred and twenty fathoms has an equable temperature during the whole year, due to the action of the Gulf Stream, while on the inshore plateau arctic animals are found identical with those occurring at similar depths north of Cape Cod, which flourish only in a variable but cold temperature. Below the warm belt the temperature is uniformly cold, and passes into that of the general abyssal region beyond it. The warm belt is but the northern extension of

the warm waters of the Gulf Stream. The belt is quite narrow at Cape Hatteras, owing to the steepness of the continental slope at that point, and gradually increases in width and depth as we go south along the trough of the Gulf Stream, its greatest width being off the Carolina and Georgia coasts. The marked influence of the currents on the fauna of the district through which they flow is well illustrated by the wholesale destruction of the tile fish and of several species of crustacea during the winter of 1881–82, as noted by Professor Verrill, of the United States Fish Commission. This was perhaps due, as he suggests, to the fact that a severe storm forced the cold water of the shallow shore-belt out to sea, and suddenly lowered the temperature of the narrow belt of outlying warm water. This belt covers an area which is probably the northern limit of many species collected in abundance during previous seasons.

We were greatly surprised at the meagreness of the fauna on the lines off Charleston and in the Gulf Stream. Owing partly to the very gradual slope of the continent towards deep water, and partly to the strong current of the Gulf Stream, which sweeps everything off the bottom along its course, there is but little food for the deep-water animals, and it was only along the edges of the Gulf Stream where mud and silt had accumulated that we made satisfactory hauls on our southern lines. What was obtained seemed to be a scanty northern extension of the fauna of the Caribbean Sea and of the Gulf of Mexico occurring between the hundred and the three-hundred-and-fifty fathom lines. It was not until we trawled on the steep slope of the Gulf Stream plateau south of Cape Hatteras, where the bottom was fine mud and globigerina ooze, that we made a rich harvest again, in striking contrast to the poor hauls along the well-swept rocky or hard bottom of the Gulf Stream to the southward. Although pteropods were very common at the surface all the way from Charleston to Cape Hatteras, they were only rarely brought up dead from the bottom; but when the steep slope south of Hatteras was reached, they again assumed a prominent part in the composition of the bottom mud.

The effect of currents on the distribution of birds has been

admirably traced by Alph. Milne-Edwards, in an interesting memoir on the fauna of the antarctic regions. He calls attention to the effect upon the distribution of penguins of icebergs carried by currents. These birds are excellent swimmers, and fond of resting on floating ice; they are prepared for long voyages, and thus may have been transplanted from a single centre to the varied localities where they are now found. In their search for food they must naturally migrate to great distances during the long antarctic winters, when they cannot carry on their usual fishing avocations. The path of the icebergs, as dependent on currents, may even enable us to trace the original penguin home. Milne-Edwards concludes that the inhospitable country of Victoria was the origin of the most characteristic animals of the antarctic region.

It will be quite possible, when sufficient material has been collected, to map out the course of the pelagic fauna; and from its bottom distribution much light will be thrown on the course of the currents. Thus the existence at Newport of Agalma, Clio, and Pneumodermon, — inhabitants of arctic seas, Labrador, Maine, and northern New England, — is direct evidence that the cold arctic current finds its way round Cape Cod to the opening of Narragansett Bay. In the same way we may trace the northern course of the Gulf Stream by the presence of Sargassum, Porpita, Leptocephali, and southern pteropods, etc., which are carried each year to the coast of southern New England. The range of southern globigerinæ and pteropods will fix the eastern limits of the Gulf Stream, as northern types determine those of the cold current along the east coast of the United States.

It is most hazardous, especially on insufficient data, to speculate upon former land connections; and yet, in many cases, the presence of identical genera of mammals seems to leave us no alternative. When, however, there are powerful currents running through the narrow channels that separate adjoining islands, or when these currents skirt the shores of island ranges and of neighboring continents, it is not always necessary to assume such an extinct continental connection. The careful study of the distribution of mammals on the islands of the

Pacific, and of their fossil remains, if any are to be found, taken in connection with the bathymetric knowledge we have lately acquired, would go far towards solving these problems. The flora alone can hardly give us the necessary facts.

The fossil marine fauna, while it can do something to help us to reconstruct the probable route of the oceanic currents, gives us no clue to land connections. Neither does the distribution of the birds, nor that of the reptiles or of the land shells, if we are to judge by the case of the West Indies, Galapagos, and Bermudas. The simplest assumption we can make for these islands is that the drift carried by the existing currents for a long period of time is amply sufficient to account for the presence of their few reptiles, mollusks, and even their mammals, and for the distribution of their flora, without the existence at any time of a direct land connection.[1]

In the case of New Zealand — an island for a long period of time disconnected from continental masses, except perhaps by its northern extension toward Australia — we account for the South American elements of its fauna by the action of the currents. As yet we know positively of no South American mammal element, and the birds have undoubtedly, as has been concluded by Captain Hutton, been derived from the north. The same would hold good of the antarctic elements. This seems a more natural explanation than the attempts made to cite plateaux of not less than two thousand fathoms in depth as proof of a former continental extension, when, for aught we know, these plateaux may be forming and increasing at the present day. No better example of the fallacy of such reasoning can be given than the phenomena of the growth of the great limestone plateaux of Yucatan and Florida, which we

[1] The changes constantly going on over the continental shelf illustrate admirably what is meant by a former land connection of continental islands. In a letter to Professor Benjamin Peirce, Superintendent of the United States Coast Survey, Professor Agassiz thus referred, in 1867, to the shoals and islands lying to the eastward and southward of Cape Cod: "The drift of the coast of New England formerly extended many miles beyond the present shores, and is still slowly washed away by the action of tides, winds, and currents. This sheet of drift once extended in unbroken continuity from Cape Ann to Cape Cod, and farther south; . . . it is constantly diminishing, and, in centuries to come, the whole peninsula of Cape Cod may disappear." (See Fig. 60.)

know to be even now growing and increasing in thickness. Yet they have been mentioned by some writers as examples of a former continental extension; and archæologists have attempted to find, on the Dolphin and Challenger ridges, the bridges, at depths of nearly two thousand fathoms, of the former land connections of Africa and Western Europe with Central and South America. There seems to be no necessity for these supposed Pacific and Atlantic continents, so long as we can explain by more simple causes the distribution of the present fauna and flora.

The marked difference between the fauna of the Red Sea and of the Mediterranean [1] clearly points to a distinct separation between these seas — greater perhaps than that once existing between the Bay of Panama and the Caribbean — previous to the time when land masses united Malta and Sicily with Africa; when Crete and Rhodes were united with Asia Minor, and there was no Eastern Mediterranean to reach the shores of Egypt and Palestine. All this shows a comparatively recent connection of Mediterranean with Atlantic waters, fully supported by the similarity, if not identity, of their marine fauna. We certainly find in the Eastern Mediterranean proof of the great changes which have taken place in the distribution of land and water during the tertiary and diluvial period. These changes, while they may in part be traced to such agencies as denudation both aerial and chemical, must also be referred to terrestrial changes, — to such volcanic or telluric agencies as slowly raise or lower definite tracts of country, when acting undisturbed through long periods of time. We have in the Eastern Mediterranean a district subject to volcanic action, the force of which is marked by the number of active and extinct volcanoes which have produced in the past and are still producing very marked changes. The zoögeographical conditions existing between the northern and southern shores of the Mediterranean do not of

[1] The rapidity with which even slight water communications affect the distribution of species is admirably shown in the case of the Suez Canal. Since its completion, several species of sharks characteristic of the Red Sea have found their way to the Mediterranean, much to the detriment of the fisheries; and a species of sea-urchin, quite common in the Red Sea, has lately been found in the Mediterranean, near Port Said.

themselves indicate a former land connection any more than the presence of the remains of African mammals at Pikermi indicates a direct communication between Greece and Africa. At the time of their greatest development, with a geographical distribution extending over Spain, Germany, Asia Minor, Persia, and India, the connections between the lands bordering on the Mediterranean may not have been materially different from what they now are.

VI.

THE PERMANENCE OF CONTINENTS AND OF OCEANIC BASINS.

THE outlines of our continents as they are defined on geographical maps give us but an imperfect idea of their true shape. An examination of the relief of the globe as developed by soundings leads to very different conclusions concerning the connection of continents and of islands from those obtained by geographical data. The soundings have developed the great terrestrial folds, of which the continents are merely such portions as are elevated above the level of the sea.[1] The latter have been modified by the action of atmospheric agencies; their height has been reduced; and the material thus worked over from the earliest times has built up the sedimentary formations which have little by little been deposited on the flanks of these ancient continental masses, extending their outlines so as to cover larger and larger portions of the original folds in successive geological periods.

As the early soundings showed the existence of a former connection between Great Britain and the Continent, so more recent explorations have enabled us to understand the true relation of Tasmania and New Zealand to the Australian continent, with its adjacent archipelago, as it probably existed in the early part of the mesozoic period. Similarly, the soundings give us some idea of the relations of the East Indian Archipelago to the Asiatic continent. We have a very different conception of the relations of the insular groups of the Pacific to each other and to the tertiary Pacific continent, so often called upon to explain difficulties in the geographical distribution of the fauna and flora of these islands. We may now speculate with some degree of certainty on the former connections of Madagascar and

[1] Such folds are probably the Challenger and Dolphin ridges of the Atlantic.

of the Mascarene Islands with Africa. The history of the lesser and greater West India Islands and of the Bahamas assumes a new interest from the explorations of the "Blake." Even the fate of Lemuria and of Atlantis can now be settled by the deep-sea soundings of the last ten years. These explorations mark a striking contrast between the continental masses, or areas of elevation, and the oceanic basins, or areas of depression,[1] both of which must always have held to each other the same approximate general relation and proportion. In other words, the continental masses and the oceanic basins, as at present defined, must be of great antiquity. The original continental masses have formed a nucleus, around the old outlines of which the principal changes in configuration have taken place.

The main outlines of the nucleus are fairly indicated by what has been called the continental shelf. Its limits in a general way are about the hundred-fathom line. Between this and the shore, and on the sea face of the continental slope beyond it, accumulations of materials, brought by the tides, currents, rivers, and winds, are constantly deposited, thus modifying the shore shelf. Within this area, or in close proximity to it, are found deposits strictly characteristic of the present epoch, and corresponding to similar deposits which must have been laid down along more ancient continental shelves from the earliest geological periods; the later deposits being in direct succession to the more ancient ones. The amount of material which still remains to be carried out to sea beyond the continental shelf, for the farther extension of our continent, is comparatively small. Our continental lands need to be twenty times their present height before they could furnish waste enough to fill the present oceanic basins. Their present elevation could hardly serve to raise the ocean depths by more than one hundred fathoms.

That there have been important oscillations in the level of large tracts of the earth from the earliest geological times, espe-

[1] Krümmel computes that the continental masses (their mean elevation above the level of the sea) and the oceanic masses are very nearly in equilibrium. (Krümmel, O. Versuch einer vergleichenden Morphologie der Meeresräume, p. 108. Leipzig, 1879.)

cially during the cainozoic period, is well known; but even if the surface of the oceans were to sink from one thousand to eighteen hundred fathoms, it would still be possible to recognize in the rough the present outline of our continents. Hence it would seem as if that outline were intimately connected with their earliest appearance and the subsequent evolution of the continent, and that these masses are not merely due to accidental denudation.

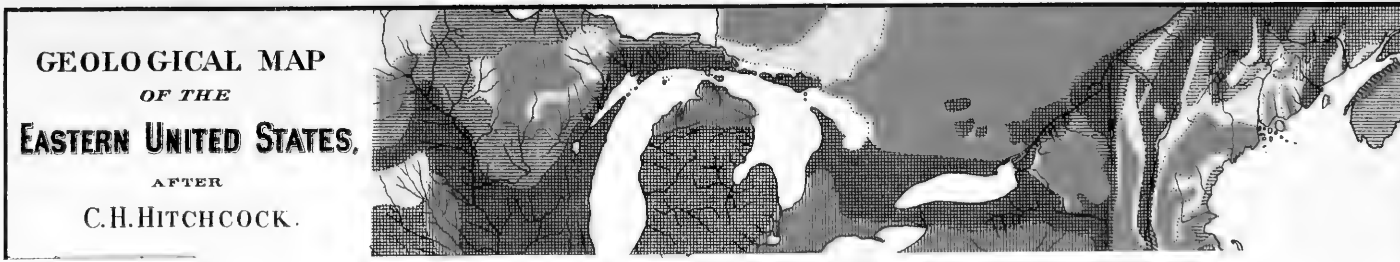
The view of the great age of our continents and oceanic basins was probably first suggested by Guyot; it was independently taken up by Dana, and Agassiz was perhaps the first to show that the results of the earlier deep-sea dredging expeditions added materially to the correctness of this view. Subsequently Thomson, Geikie, and Carpenter elaborated this theory, which of late has gained ground among geologists, and has found its most recent advocate in Wallace.

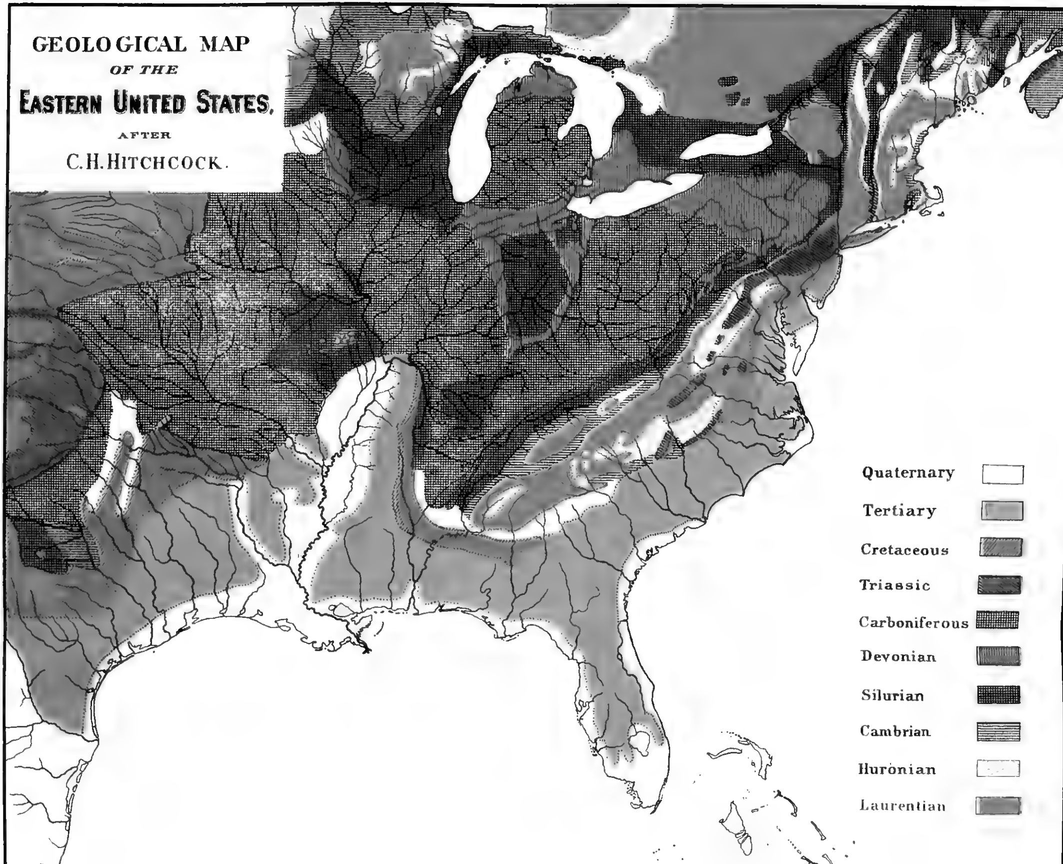
The geological structure of the different islands of the world enables us to judge whether they are mere volcanic peaks, the highest points of districts subject to cataclysmic local elevations, or whether they are parts of larger masses of land first built up by sedimentary deposits,[1] and gradually reduced by denudation to their present size,—the remains, in fact, of great submarine banks, indicating in a certain measure the former outlines of the land. The extent of this denudation has been calculated in some cases; and so powerful is its agency, that, if carried on during long periods of time, it may transform oceanic regions into continental masses, and the reverse. This may have been the case in the earliest periods of the formation of the earth's crust, when the precipitation was much greater than now; but we have as yet no evidence of any such transposition of continental masses and of oceanic basins since the mesozoic period. If such pre-archæan continents existed, they, like the continents from which the materials for the mesozoic and tertiary deposits were derived, have left no traces.

[1] The careful examination of St. Paul's rocks by the Abbé Renard, for instance, clearly proves this island to be of volcanic origin, like many other oceanic islands, having, as shown by Geikie, nothing whatever to do with the remains of a former continent, the long lost Atlantis.

We may go back to the time when all the water of our oceans, rivers, and lakes existed only as vapor suspended round the heated earth, — forming, as has been said by Mallet, an atmosphere of steam, producing greater extremes of light and heat than are known to-day, enormous differences between summer and winter, and very striking contrasts between the polar and equatorial regions. When water was first deposited, on the cooling of the crust, ice may have existed at the poles, while the equatorial seas may still have been too hot to sustain life. Such contrasts in temperature must have occasioned oceanic currents unparalleled in the present state of the globe. Consequently the disintegration of the rocks forming the crust of the globe, subjected as they were to the torrential rains, the powerful currents, and the extreme solvent powers of water at the high temperatures then existing, must have been far greater and more rapid than now. It is not surprising, therefore, if we find the earlier stratified rocks deposited through agencies similar to those now acting, and yet formed under conditions having no exact parallel in our times.

The material brought down to the sea from the basin of the Mississippi has been accurately measured by Humphreys and Abbott, and their report states that it would require five millions of years, at the present rate of denudation, to carry off a thickness of one hundred feet. As far as we can judge from the deposits off the mouth of the Mississippi, the mud brought down, while it has made an extensive submarine deposit, projecting far beyond the general continental line, has not been detected beyond a distance of about one hundred miles from the passes. To this must be added the matter held in solution by rain-water, the amount of which depends principally upon the nature of the rocks forming a hydrographic basin. Frankland has calculated that for every 100,000 tons of water there were 39 tons of carbonate of lime and magnesia, and 1,018 tons of sulphates; so that, according to Reade, it would take twenty-five millions of years to accumulate the sulphates now in the sea, and only 480,000 years to renew the carbonates; but that it would take about two hundred millions of years to replace the existing supply of chlorides. The carbonates have, of course, been con-


GEOLOGICAL MAP
OF THE
EASTERN UNITED STATES,
AFTER
C. H. HITCHCOCK.


GEOLOGICAL MAP
OF THE
EASTERN UNITED STATES,
AFTER
C.H. HITCHCOCK.
Quaternary
Tertiary
Cretaceous
Triassic
Carboniferous
Devonian
Silurian
Cambrian
Huronian
Laurentian

stantly used up by the formation of the immense beds of limestone which have been deposited from the mesozoic to the present time.

Professor Dittmar, in a lecture delivered before the Glasgow Philosophical Society, formed an estimate based upon data given by Boguslawski regarding the solids introduced into the ocean by rivers; from which he calculated that it would require nearly twelve hundred years to increase the percentage of carbonate of lime in the ocean by one per cent of its present value, supposing no part of what is added were precipitated by animal life.

We know that a portion of the Spitzbergen coast is rising, and that some points of the Scandinavian peninsula must have been raised one hundred and fifty metres. Holland, on the contrary, shows a sinking of its shores. Darwin's observations on the elevation of parts of the west coast of South America are well known. I have myself visited the principal localities about Coquimbo, and have found evidence that the maximum elevation probably took place near the latitude of Pisagua, gradually diminishing farther south. We may perhaps regard as remnants of a sea bottom the sloping plains extending from the nitrate beds of Pisagua to the southern parts of Chili, parallel with the Coast Range, until it passes into the Chiloe Archipelago. The terraces all along the coast, such as have been noted by Darwin, plainly show the extent of the elevation, or may have been a part of the movement resulting in the separation of the Gulf of Mexico and of the Caribbean Sea from the Pacific.

Let us examine a geological map of North America. We see that, during the earliest geological times, (Fig. 62) the North American continent was indicated in its broad outlines by a great telluric fold, — an immense V-shaped archæan continent, situated mainly in British North America, one arm reaching northeastward to Labrador, and the other northwestward from Lake Superior. In addition to this continental nucleus, smaller mountain ranges — the Rocky Mountains and Appalachian and other isolated areas — existed, indicating the presence of a submarine American plateau, upon which the

palæozoic, mesozoic, and subsequent formations were deposited.

All the evidence we have seems to show that up to the time of the cretaceous, the sedimentary rocks, in spite of their enormous thickness, were deposited in comparatively shallow seas. We find in them abundance of animal remains, fossils, and even tracks, as well as ripple-marks, indicating the proximity of land

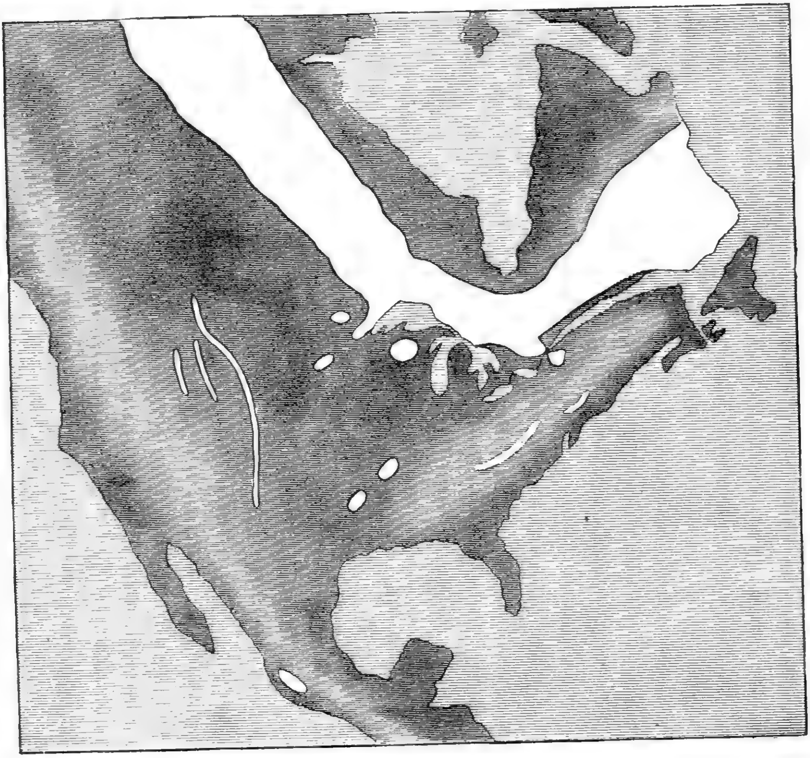


Fig. 62. — Archæan Map of North America. (Dana.)

or of continental islands. Undoubtedly, in earlier geological periods there have been invasions upon as well as withdrawals of the sea from the low continental masses resting upon the continental folds, and these invasions have left probably large shallow inland seas upon these folds. Then, as now, there must have been a considerable deposit of finer material upon the outer edge of the continental masses then forming, which

has been buried under coarser material by the advance of the continents as they became older. The conclusion seems inevitable, that the sedimentary rocks attained their great thickness in areas of regular subsidence, the subsidence being due to the deposition of material along the shore lines. We know of no other cause to account for the deepening of the seas, the action of the waves being restricted to a very limited depth.

The effect of the deposition of such immense plateaux of limestone as the Florida peninsula, the Yucatan Bank, the Pedro Bank, and the smaller plateau along the West India Islands, should be to cause a gradual depression over the whole of the area of the Caribbean and of the Gulf of Mexico. But all the indications we have from the deposits of recent formations in Florida, in the West India Islands, and at the Isthmus of Panama, show, on the contrary, that they are in an area of elevation due to volcanic agencies, still more or less active at the present day. In like manner, the transfer of such huge masses of silt as we have at the mouth of the Mississippi and near Cape Hatteras should theoretically be accompanied by a corresponding subsidence. We can only assert, however, that the mud of the Mississippi is slowly filling the deep basin off its mouth, and that it has been doing this for some time past.

The distance to which the Mississippi mud is carried from the shore shows us how far such deposits, representing immense areas of denudation, may share in forming additions to continental masses, and determining their relations to the formations immediately preceding them. According to the soundings of the "Blake," the presence of Mississippi mud cannot be detected more than one hundred miles from its mouth; beyond that we find the usual deep-sea specimens characteristic of the bottom of the Gulf of Mexico. Off Cape Hatteras, also, an immense slope of fine detritus has been formed by the wearing action of the Gulf Stream. As far as agencies now at work are concerned, the forces acting to-day are mainly efficient along continental masses and along the shores of islands, and must of necessity have left the basins separating the continental masses practically intact, except along their margins.

If a pressure of two thousand tons to the square foot is sufficient to render rock viscous, it would follow that, at a short distance below the bottom of our oceanic basins, the rocks of which are subject to a pressure of nearly seven thousand tons to the square foot, we should soon come to a viscous layer possessing a very high temperature. Now as the upper layer of the rocks of the ocean bottom has a temperature nearly approaching the freezing point, this alone would, according to Mr. Gardner, cause the bottom of the ocean, being under a greater weight than the rocks near the shores, to remain more permanent. The tension of the viscous layer, however, would be very great, and would find relief along lines of least pressure, in ridges or along shores of land masses, as is the case with volcanic outbursts or with lines of elevation. For this reason we should naturally seek the lines of greatest elevation in the later geological periods. As is well known, the highest mountains are the most recent, and nowhere do we find such great altitudes as in the vicinity of shore lines: as along the west coast of South America, or near the coast of Japan, where the depth is over 4,300 fathoms; or off Porto Rico where the elevation above and below the level of the sea is not less than thirty-two thousand feet.

Many attempts have been made to reconstruct the geography at different geological periods, and to trace the paths of the oceanic currents. These attempts have been more or less successful, and are probably, in our present state of knowledge, as accurate as the maps of the world made by the ancients compared with the results of modern geodesy. We need not go back to the earlier geological periods, beyond stating in a general way that, as far as we know, the outline only of the continents existed at the time of the silurian, — the skeleton, the framework, as it were, upon which have grown all subsequent additions. This skeleton allowed a free equatorial circulation, broken by larger or smaller islands in the region of the East Indian Archipelago, impeded in a similar way by huge islands on the east and west coasts of equatorial Africa, and by an archipelago occupying the whole northern extremity of South and Central America. Europe was only a series of islands; the

greater part of Northern Asia was swept by a westerly current; and we may imagine a North Atlantic equatorial current deflected so as to reach the arctic region, the main branch finding its way into the Pacific to form a part of the Pacific equatorial current; and a second current from the equatorial Atlantic ramifying along the eastern coast of the South American Archipelago.

If we omit the intervening periods and pass over to an examination of the map of the world at the time of the chalk, we shall find our continents greatly increased in size. The littoral and shallow-water deposits, which have formed the devonian, the carboniferous, the lias, the jura, have united many of the older islands. They had perhaps given to Africa much the outline which it now has, with the exception of the broad passage which was still open to the Indian current, through Arabia and North Africa, to the Atlantic. The European Archipelago consisted of large islands. The northern part of Asia was still disconnected from China, Siam, and India by a wide strait, through which flowed a current joining that in the Indian Ocean, and forming a large inland sea, connecting the Caspian, Black, Aral, and Baikal Seas. The islands forming the southern extremity of South America had become connected, but there was probably little change in the outlines of the archipelago forming the northern part of South and Central America.

But North America itself has greatly changed. There is a deep bay extending from the Gulf of Mexico far up towards the sources of the Missouri, while the shores of Mexico, of the greater part of Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, North Carolina, parts of Virginia, and New Jersey are still swept by the returning Atlantic equatorial stream, much as the shores of the Gulf of Mexico are nowadays. Only a small part of the North Atlantic equatorial current finds its way now through the Central American and South American archipelagoes into the Pacific, the greater part of it raising the temperature of the shores of North America as high as that of the Gulf of Mexico at the present day. Undoubtedly the combined influence of this equatorial drift in its eastern extension and of the Gulf Stream was then far more powerful in raising the

climate of the arctic regions than it is to-day, and was felt not merely on the coast of Iceland, the Færöes, Norway, Spitzbergen, and along the north shore of Siberia, but also in the temperature of Greenland, making it possible for a flora similar to that of the temperate zones to flourish there.

During the tertiary period, the inland sea of Western Asia became greatly reduced in extent; and the connection between the Indian Ocean and the China Seas, across the central part of China and the northern part of India, Arabia, Asia Minor, and Palestine, closed the free access of the Indian current from the Mediterranean. South America, with the exception of the pampas and Amazonian gulfs, had practically assumed its present outline; while the shore line of the southern part of North America had more nearly approached the existing line of the Gulf of Mexico. There was thus a less amount of water heaped up in a smaller Gulf of Mexico, and a corresponding decrease in the influence of the Gulf Stream of the tertiary period over the climate of the arctic region, till in our own epoch the effect of this equatorial current is practically felt only on the eastern part of the North Atlantic, reaching also toward Nova Zembla and the northern shores of Siberia. With the cooling of the arctic region a greater influence was exerted by the cold current which found its way from the North Pole towards the equator along the eastern coast of North America, thus driving the warm water towards the eastern part of the North Atlantic Ocean.

The soundings of the "Blake" during the dredging season of 1880 developed some striking features in the profile of the slope which extends eastward from the shore along the Atlantic coast, south of Cape Hatteras as far as the northern extremity of Florida. The few lines run in 1880 normal to the coast, and the line run parallel to the so-called axis of the Gulf Stream, showed the probable existence of an immense submarine plateau, of which the eastern edge had not been reached, or else the soundings indicated a very slight slope from the shore to deep water along the whole coast line south of Cape Hatteras to the latitude of the Bahamas.

Everywhere else along the Atlantic coast of the United States

north of Cape Hatteras, and in the Gulf of Mexico, the continental line of one hundred fathoms is most plainly marked, forming the upper edge of the more or less abrupt descent leading into deep water with a regular inclination. Owing to the absence of this hundred-fathom line south of Cape Hatteras, it became an interesting problem to trace the exact profile of that part of the coast, and to continue it into deep water. The season of 1881 was spent by Commander Bartlett in the "Blake," under the direction of the Hon. Carlile P. Patterson, the late Superintendent of the Coast Survey, in running a number of lines normal to the coast, south of Cape Hatteras and north of the Bahamas, and carrying them into deep water. The Superintendent of the Coast Survey has kindly allowed me to make use of the results of Commander Bartlett in connection with my report of the dredging expeditions of the "Blake."[1]

As was to a certain extent anticipated, the lines developed an immense plateau, of a triangular shape, reaching from the Bahamas to a point immediately south of Cape Hatteras, where this plateau passes into the northern continental shelf, limited by the hundred-fathom line.

The eastern edge of this plateau is from three hundred to three hundred and fifty miles from the coast, and with an abrupt slope passes into deep water. For the sake of brevity I shall call it the "Blake Plateau." (See Figs. 56, 176.) The eastern edge of the slope of the Blake Plateau commences at an average depth of at least four hundred fathoms, so that the general profile of the lines carried normally across it shows a gradual incline from the shore to a depth of about fifty fathoms, then a somewhat abrupt slope to a depth of about four

[1] These lines have, during the season of 1882–83, been extended south of the Bahamas as far as Porto Rico. Under the direction of Professor Hilgard, the "Blake," in command of Lieutenant-Commander Brownson, U. S. N., ran normals into deep water, showing that the Blake Plateau developed by Commander Bartlett commences slightly to the westward of Great Abaco, and extends thence northward. (See Figs. 56, 176.) Lieutenant-Commander Brownson proved further that to the south the eastern edge of the Bahama Bank ran but a short distance seaward parallel to the general line of the outer row of islands of the group, till it united with the plateau upon which Porto Rico and the Caribbean Islands crop out, leaving probably one or two deep passages extending towards the old Bahama Channel north of San Domingo and Cuba, leading to the Windward Passage.

hundred fathoms, then a very gentle descent to the edge of the sharp, steep slope forming the outer eastern edge of the Blake Plateau, at a depth of nearly six hundred fathoms.

It is interesting to speculate how this peculiar profile, so different from that of any other part of our coast, was formed. The explanation to my mind is comparatively simple. The present outer eastern edge of the Blake Plateau, which is now at a depth of six hundred fathoms, was at one time at a much higher level. In fact, I assume that this slope probably represents the remnant of the slope formed at the time when it began at the hundred-fathom line, and that this trough with unequal sides has been worn away by the action of the Gulf Stream acting upon the Blake Plateau from a geological time which we can trace with a certain degree of accuracy.

We may also imagine the slope off the Carolinas and Georgia to be due, not to the wearing action of the Gulf Stream along the surface of the ancient continental plateau, but to the deposition of a large amount of silt from the remains of pelagic animals, which has gradually formed the bank — the Blake Plateau — occupying the angle between the northern extremity of the Bahama Bank and Cape Hatteras.

In the one case, the hundred-fathom line existed formerly far out to sea beyond its present position, along a line now represented by about the five-hundred-fathom line; in the other case, the hundred-fathom line was nearer the coast, perhaps even within the present shore. The accumulated growth of calcareous animals together with the deposition of pelagic material has gradually enlarged the outer edge of the former continental plateau, and thus the distinct line of demarcation usually formed by the hundred-fathom line has been obliterated along that portion of our coast. To this may be due the formation of the Blake Plateau.

In other words, the old continental line extended at least two hundred and fifty to three hundred miles farther to the eastward, forming a huge plateau, the hundred-fathom line of which was found where the six-hundred-fathom line now runs, and stretched so far south as to include the Bahamas and Cuba in this great submarine plateau. The elevation of the Blake Pla-

teau probably dates back to the end of the cretaceous period, the time when the plateau of Mexico was raised, by which whatever communication may have existed between the waters of the Atlantic and those of the Pacific was cut off, and there were formed a number of islands, more or less extensive, in the range of the Greater or Lesser Antilles.

We may attempt from the topography of the bottom of the Gulf of Mexico, of the Straits of Florida, and of the ocean off the east coast of the Southern States, to reconstruct the ancient course of the Gulf Stream from the time of the cretaceous, and to speculate upon its action in modifying the topography of the continental shelf which runs from the Bahamas to Cape Hatteras.

At that time the Gulf Stream, passing between Yucatan, then a submarine plateau of comparatively moderate depth, and Cuba, furrowed the deep channel, one thousand fathoms or more, which now separates Yucatan from Cuba. The Gulf Stream then lost itself northward in a Mississippi bay, and spread fan-shaped partly over the submarine plateau of Florida. It brought, however, an accession of materials, by the deposition of which the plateaux of Yucatan and of Florida were slowly built up, and which also supplied food to the innumerable marine animals whose former existence is proved by the structure of the very plateau upon which they must have lived. The Gulf Stream thus contracted its own boundaries, and was forced into the narrower channel it had constructed between Yucatan and Cuba. As a consequence, it cut an ever deepening trough, and in proportion as Florida rose from the sea it was also compelled to find an outlet for the mass of water by which the Florida peninsula had been covered. It naturally followed the track of least resistance, and forced its way up-hill over the lowest part of the plateau, the southern point of Florida, through the then comparatively shallow passage of the Straits of Bemini, which it must have deepened by degrees as Florida was building up.

The mass of water which in the early part of the tertiary period forced its way north, partly up the Mississippi, and partly east over the peninsula of Florida, was little by little confined to

the single channel of the Straits of Bemini, and then the whole mass of the Gulf Stream flowed northward over the shallow Blake Plateau extending north of the Bahamas to Cape Hatteras. It is this part of the Blake Plateau which, if I am right in tracing its past history, has been worn away by the unceasing flow of the Gulf Stream.

The Gulf Stream now flows north of the Straits of Bemini upon this comparatively shallow submarine Blake Plateau,[1] with an average depth of about four hundred and fifty fathoms, and finally pours into the deep water of the Atlantic over the edge of the steep slope south of Cape Hatteras. At the same time it precipitates on this slope all the silt it has carried on its bottom, accumulated mainly through the decay of pelagic material and the wearing action of the Gulf Stream in its course northward. A similar action, but on a smaller scale, also takes place on the steep western and northeastern slopes of the Yucatan Bank. The shallow surface waters of a part of the Stream pour over this bank, and deposit on its slopes the silt held in suspension, and whatever materials are gathered along its course by its action upon the smaller banks and reefs of the great bank itself.

We have, unfortunately, no very definite data regarding the wearing action of water so densely charged with silt as is shown by the immense quantity deposited by the Gulf Stream on the northeastern edge of the Blake Plateau, just south of Cape Hatteras. The Mississippi, with a depth of say five fathoms, and a velocity not much greater than that of the Gulf Stream, has in a couple of years dug out a depth of at least eighty feet a short distance back of its bar. What may be the wearing action of a mighty river like the Gulf Stream, having an average depth of three hundred and fifty fathoms, and a breadth of some fifty to seventy-five miles, with a velocity of five miles, it is difficult to say. Supposing, however, that this wearing action is no greater than the aerial denudation over the area of the Mississippi drainage basin, — that is, at the rate of one foot in six thousand years, and it certainly is not too much to assume the

[1] The different shades on the map (see Fig. 176) correspond with the respective velocities of 1, 2, 3, 4, and 5 knots per hour.

same amount for the grinding action of the Gulf Stream, — this would give us a period of about ten millions of years since the termination of the cretaceous period. This estimate is probably far too high, judging by what we know of the wearing action of water in hydraulic sluices; we have a safer estimate in a period of five millions of years as denoting the time which has elapsed since the beginning of the tertiary. If we assume with Ramsay that this represents about one tenth of the time which may have elapsed since life appeared on the earth, we should have a total of not more than fifty millions of years since the first appearance of life upon this globe. To this must be added, as indicating the age of the globe, whatever time mathematicians think was necessary to reduce the globe from its primitive state to a condition fit for animal life.

VII.

DEEP-SEA FORMATIONS.

The study of oceanic deposits has materially modified many of our notions regarding the mode of formation of the marine deposits of former geological periods. These deposits constitute a considerable portion of the crust of the earth, and we may to-day, as has well been said by Saporta, study their mode of formation, like that of the beds of the chalk, of the oölite, of the miocene, and of the later tertiaries, as plainly as if we had lived and witnessed the phenomena which have left their record in the geological time tables.[1]

"It is to-day the privilege of the special student to decipher the history of the past with a certain boldness, and from the careful study of the present to picture to himself the most ancient phenomena. Beds composed of globigerinæ, of pteropods, of fine sand, or of ooze, have long been known to the geologist; but their interpretation by the knowledge of to-day calls up pictures of the past which his predecessors could never have imagined."

Granting the great age of our oceanic basins, it follows that while there were in earlier geological periods deep-sea deposits similar to those laid down to-day on the floors of our oceans, yet they constitute but a small part of the beds which go to make up the thickness of the earth's crust. Abyssal deposits must always have been formed near the sea-edge of the continental nuclei, or in the track of the principal currents of those days; while on the continental folds were deposited in succession the formations which have built up our continental areas. Then, as to-day, the coarser materials were deposited within a short distance of the existing shore line, while the coarser sands

[1] Saporta, Gaston de, Revue de Deux Mondes.

and finer clays were carried subsequently to longer distances, and finally to depths of nearly six or seven hundred fathoms. The finest shore deposits are not known to extend beyond four hundred miles. Along the course of currents fine silt will be deposited on the farther slope of ridges over which they pass, as in the Windward Passage, or on the sea-face of the continental slope off Hatteras, at the foot of the falls of the Gulf Stream, if I may so call that slope. Greensand appears to-day to be deposited in the eddies of the Gulf Stream. Rounded pebbles with conchoidal fractures are found in the West Indies at considerable depths. Their shape is probably due to the action of the comparatively warm water of those depths upon the fragments of rocks disintegrated from their original layers. Manganese nodules and incrustations are met only in deep water. In the vicinity of coral islands extensive deposits of comparatively coarse limestones often run to great depths, as off the western Florida Bank; quite large pieces of such limestone were brought up by the "Blake" from a depth of about fifteen hundred fathoms. Nullipores extend to a depth of one hundred and fifty-five fathoms. We find large forests of the larger kinds of bryozoa at a depth of from one hundred to two hundred fathoms. Deposits of sand, of groves of bryozoa, or of nullipore limestone, can therefore be found within the limits of the deep-sea fauna.

The plateaux of limestone which form the submarine base of the Florida and Yucatan banks are examples of deep-water limestone deposits, the like of which we know to have been formed in the West Indies during cretaceous and tertiary times, and to have been elevated to considerable heights, as, for instance, in Cuba, Jamaica, San Domingo, Barbados, and other West India Islands.

By deep-sea deposits of past ages we of course mean those deposits in which animals now characteristic of the deep-sea fauna have been found; that is, such deposits as do not in our day seem to play any important part in modifying the outline of our continents; such deep-sea deposits consist exclusively of globigerina, diatom, biloculina, and radiolarian ooze, and of the abyssal red clay.

The littoral fauna of to-day occupies a somewhat narrow belt within the hundred-fathom line, at no very great distance from the shore; in fact, inside of what has been termed the continental line (one-hundred-fathom line), while the rest of the bottom of the ocean is occupied by the continental and the strictly deep-sea fauna.

Littoral deposits take place under constantly changing conditions, and are subject to violent perturbations, which disturb and modify the stratification. Deep-sea formations, on the contrary, must of necessity be subject to less interference, and therefore acquire a greater thickness. If this was really the case with the older formations, those which — like some of the limestones — are of deep-sea origin, will be found to be much thicker than the contemporaneous littoral deposits. This we may assert to be the case. Care must of course be taken, as has been urged by Fuchs, to compare such deposits as are comparable, and not to draw deductions from phenomena which have nothing in common. A coral fauna, a brachiopod fauna, and an ammonite fauna give us no terms of comparison. We may even have marked contrasts, as between eocene mammalia and cretaceous saurians, while a common factor is presented by the flora of the two periods. Invertebrates pass from the jura to the chalk without presenting striking contrasts, while among fishes the transition from ganoids to teleosteans shows the relationship in one case to be with the past, in the other with the future. They are the young and the old generations. The effect of surroundings is of course very different upon organisms of various classes at successive periods of their geological and palæontological development. The attempt, made by Fuchs, to identify the deep-sea formations of former geological periods from the facies of the fauna is subject to the same difficulties that are found in determining the upper and lower limits of the abyssal fauna. These difficulties are due to the enormous bathymetrical range of many species, which were at first regarded as strictly abyssal, but have subsequently been proved to extend almost into the confines of the littoral zone.

By far the greater number of the marine forms characteristic

of the oceanic fauna and flora of the present day are found within the hundred-fathom line. In attempting either to define or to contrast the fauna of the shores and of the deep, we find a neutral region, characterized perhaps by no forms strictly its own, but in which the stragglers from each zone flourish, and nothing typical either of the littoral or of the deep-sea fauna is any longer found.

In many localities where deep-sea deposits are taking place at the present day, the distance from the coast is often not very great, especially in volcanic regions. Along the face of the whole Atlantic coast from the Bahamas to St. Thomas, the line between the continental curve and the two-thousand-fathom line is nowhere more than fifteen miles distant. We cannot therefore infer that because a formation has been deposited parallel to a continental coast it must necessarily be a shallow-water formation. What to-day would be called continental formations, from the character of their fauna, lie within the limits of say three hundred and fifty to seven hundred and fifty, or perhaps one thousand fathoms. But as the character of the fauna in its turn depends mainly upon the constitution of the bottom, this interdependence introduces many variable elements. There is no greater contrast than that which exists between the fauna living upon the recent limestones of the steep slopes of the Florida plateau and that found at similar depths in the calcareous ooze of the trough of the Gulf Stream in localities not many miles distant.

We are justified in considering deposits containing large amounts of globigerina, radiolarian, and diatom mud as pelagic deposits laid down at certain distances from land in considerable depths; but, as these animals are pelagic, the possibility exists of their being found in shallow deposits. Pelagic foraminifera are found in the muds which have been brought down by rivers into the Gulf of Mexico. The modern greensand found off the coast of the Carolinas on the edge of the Gulf Stream occurs in depths of less than fifty fathoms. Arenaceous foraminifera are to-day only found in large quantities in deep water.

If, as Wallich suggests, flints are now formed only in deep-sea

deposits, this fact would go far towards settling the question of the depths of the cretaceous sea. Along the coast range of Chili, in the nitrate districts, the position of the flint beds shows that they were deposited in estuaries. Judging by the analogy of their recent representatives, the siliceous sponges so common in many of the formations must have lived at considerable depths. The presence of pentacrinoids and their allies, which were not attached to the bottom, but like those of to-day lived imbedded in mud or ooze, denotes deep water; while fossil types with a strong, powerful root may give evidence of shallower waters.

Were we to decide by the size of the fossils, the smallness of the mollusks and echinoderms collected from certain beds, like those of the triassic beds of St. Cassian, would point to a deep-sea fauna.

The liassic beds of Hierlatz near Hallstadt in Austria are said by Fuchs to be analogous perhaps to massive calcareous deposits like the Pourtalès Plateau of Florida. Massive whitish, subcrystalline limestone occurs in them, built up almost entirely of small brachiopods; but deep-sea corals are wanting in these beds.

Many of the cephalopods of to-day are like the argonaut, pelagic, or else they are deep-sea types, like nautilus and spirula. The Eryon-like crustacea brought up by the dredge are all inhabitants of considerable depths, and the macruroids, Ophidiidæ, and the like, are deep-water fishes. We should constantly bear in mind that the absence of certain types of invertebrates may be very marked, owing to the disappearance of the more soluble tests from beds in which the heavier and less soluble remains are still to be found. So that in many formations we probably find only a part of the fauna which, when in its most flourishing condition must have characterized them. The fauna of the deposits of the old red sandstone of the Connecticut River indicates that it lived in shallow water, while deposits rich in remains of belemnites, etc., were formed in deep waters.

The scarcity of vertebrate bones in dredgings is very marked. Mr. Pourtalès, who seems to have been more fortunate than all

others, dredged a few manatee ribs in the Straits of Florida. Neither the Fish Commission nor the "Blake" has been equally successful. The "Challenger," however, dredged thousands of sharks' teeth and cetacean bones in 2,300 to 2,800 fathoms. They were principally found in restricted areas, far removed from land, in the abyssal red-clay regions, where the rate of accumulation is very slow, and where such bones are not likely to be buried by detritus coming from the shores, or by the more rapid deposition going on along continental shelves. These deposits may be analogous to the bone beds of the corniferous, or perhaps to the phosphate beds of South Carolina, or the Cambridge coprolite beds. On the east coast of the United States, and in the Gulf of Mexico and the Caribbean, sharks' teeth have been dredged, but rarely. Either the sharks of former times were much more numerous, or, as has been suggested by Professor Verrill, their remains, as well as those of fishes [1] and other vertebrates, were not immediately devoured by other inhabitants of the deep sea. One would also expect that the bones of porpoises would be common in localities where they are often seen sporting by hundreds, as along the Windward Islands. Yet none were dredged by the "Blake."

An examination of the fossils from many of the raised sea-beaches reveals types which the late explorations have shown to be deep-sea forms. Seguenza was the first, in studying the pliocene deposits of southern Italy, to show that some of them were deposited in deep water. He suggested that the foraminiferous, bryozoan, coral, and radiolarian beds were deposits which must have been laid down at considerable depths; he was led to this conclusion by a comparison of their fossils with the animals of the present day found at great depths. Before the recent deep-sea investigations, geologists were misled by the strange forms contained in many of the foraminiferal deep-sea deposits of the tertiary period, and looked upon these deposits as much older than they were in reality.

Fuchs has also compared other beds of the tertiary, on account of their characteristic fossils, with certain deep-sea deposits. The

[1] Otoliths of fishes occur not unfrequently in the fine muds of the Gulf of Mexico.

flysch, which forms so important a part in the geology of southern Europe, he thinks must have been a deep water deposit. The beds of the mesozoic period in which ammonites are found, Fuchs looks upon as deep-water formations, because in all distinctly shallow-water beds of that time no ammonites have been found.

From the time of the earliest examination of the globigerina mud of the Atlantic, by Bailey and Ehrenberg, that deposit has been compared to the chalk; and since the time of deep-sea investigations, the white chalk, with its globigerinæ, Hexactinellidæ, and peculiar echinoderms, has always been regarded as an antique type of deep-sea deposits. Jeffreys, on the contrary, assumes it to be a shallow-water formation from the study of the mollusks. His reasons are that the foraminifera of the chalk are many of them pelagic, and might therefore be found in littoral or shallow-water deposits; that globigerina ooze contains a large percentage of silica, while the chalk is nearly pure carbonate of lime; that the mollusca of the chalk are all littoral types; and that the so-called deep-sea genera are wanting. Yet we find in the chalk such genera as Terebratula, Lima, Pecten, and Spondylus, all of which are found in very deep water,—to a depth of fourteen hundred and fifty fathoms. While admitting that pelagic foraminifera frequently occur in littoral deposits, it seems impossible that some of the beds of foraminifera of great thickness should have been deposited otherwise than in deep water. Foraminifera ought to serve as excellent guides in identifying deep-sea formations, since genera like Cristellaria, Marginulina, Clavulina, Nodosaria, and others, with arenaceous and siliceous tests, occur in the seas of to-day, principally in deeper waters.

The present chemical constitution of the chalk is also not the one in which it was deposited, the siliceous particles having probably been concentrated as flint. As regards the fauna, the mollusks are not so good a guide as either the sponges or the echini, the representatives of both of which — Hexactinellidæ, Ananchytidæ, Pourtalesiæ, Saleniæ, and Echinothuriæ — are eminently deep-sea types. That many of the molluscan forms which lived in the chalk have been dissolved as arago-

nite there is no doubt,[1] but the presence in the chalk of deep-sea brachiopods, cephalopods, and crustacea, tends to prove the deep-sea nature of the old white chalk.

We should, however, bear in mind that at the present day the distinctions made to determine faunistic regions are often based on the presence or absence of certain species, and not of genera. Genera have a far wider range both geographically and bathymetrically, and can only be used for such comparisons with the greatest care. It would certainly be impossible to find anywhere to-day a littoral fauna with the facies of the characteristic chalk.

It is difficult to institute a comparison of the globigerina ooze with the chalk proper, as from the length of time the latter has been exposed to the action of the atmosphere its composition must have changed materially either by solution or metamorphosis.[2]

The difference in the analysis of the chalk and of the globigerina ooze consists mainly in the fact that there is more carbonate of lime and less alumina in the former; while the flint nodules in the chalk are replaced perhaps by the large amount of silica in the globigerina ooze. Coccoliths and coccospheres, similar to those detected by Wallich in the chalk, also occur in the deep soundings.

Murray and Renard consider that "chalk must be regarded as having been laid down rather along the border of a continent

[1] This was discovered by Hébert. In the seas of the present day the shells of pteropods and globigerinæ are, as has been discovered by the "Challenger," dissolved beyond a certain depth. Pteropod ooze is not found in depths greater than fifteen hundred fathoms, and globigerina ooze disappears in its turn at about twenty-five hundred fathoms.

[2] The solvent power of the ocean during some of the earlier geological deposits seems to have been far less than in later times. What the cause is which has acted so much more vigorously in later periods, and caused the disappearance of aragonitic organisms in the modern limestones, is not known. "Silica has been removed and segregated into flints from the white chalk. Other chalks have become cherty. Siliceous skeletons of sponges are replaced by calcite, calcite by silica, and aragonite has been entirely dissolved away." Professor Dittmar suggests that the dissolving of shells may be due to the action of sea-water itself, as after a sufficient length of time it can take up an amount of lime additional to what it already contains. But the carbonic acid present in sea-water undoubtedly plays some part in this dissolving process. Pteropod shells, in all possible stages of decay and solution, form an important element in the deeper deposits of the Gulf of Mexico.

than in a true oceanic area."[1] There is no proof that massive formations are deposited anywhere except along continental shelves, while at the greatest depth we may find the true red clay, the result of chemical decomposition.

Mr. J. S. Gardner considers the blue mud found around shores and in partially closed seas, and passing into a deep-sea deposit at a distance from land, as the equivalent of the gault. The gault has among its mollusca, Leda, Limopsis, and Dentalium, all well-known deep-sea mollusca. Its foraminifera and echinoderms likewise are deep-water types. The upper gault represents a deeper sea; blue muds are replaced by green muds; from that we pass to chalk marl, which is apparently a sort of globigerina ooze, and finally to the white chalk, with its great extent and thickness, which proclaim it to be an oceanic or a deep-water deposit; and there seems to be nothing with which it can be compared except globigerina ooze.

Professor Liversidge describes a chalk formation from New Zealand, consisting of eighty-one per cent of carbonate of lime and seven per cent of silica. This contains, as is stated by Brady, species of foraminifera now found in deep-sea specimens of globigerina ooze from fifteen hundred to two thousand fathoms in depth in the South Pacific. The origin of the New Britain chalk is not known, but it is probably recent; the specimens are thrown up on beaches after storms. White chalk contains ninety-eight per cent of carbonate of lime, and gray chalk ninety-four per cent. The "Blake" also dredged off Nuevitas, in 994 fathoms, recent chalk which Murray says is more like white chalk than anything he has seen.

Chalk is certainly not derived from the disintegration of coral reefs, although we frequently find patches of rock associated with coral reefs closely resembling true chalk, both in texture and composition, — as, for instance, in the so-called modern chalk of Oahu. The percentage of carbonate of lime composing reef corals[2] varies from ninety-five to ninety-eight; this

[1] Chalk may be forming at very great depths close to a continent. See the analysis of the modern chalk collected off Nuevitas in 994 fathoms. (Murray, Bull. M. C. Z. XII., No. 2.)

[2] Sharples gives the following percentages of carbonate of lime: Oculina, 95.37; Manicina, 96.54; Madrepora, 97.19; Siderastrea, 97.30; Millepora, 97.46; Agaricia, 97.73. *Madrepora pal-*

is larger than the percentage of lime characteristic of true chalk.

On the western edge of the Florida Bank, northward of the Tortugas, sponges occur in abundance, and the trawl would constantly come up from a depth of one hundred fathoms filled with masses of sponges, both siliceous and calcareous, from a modern limestone bottom. Masses of fossil sponges occur in the jurassic beds of southern Germany and Switzerland, made up of calcified skeletons of Hexactinellidæ and of Lithistidæ. Siliceous sponges are also common in the white chalk of England and France. Calcareous sponges are very abundant in some of the shallow-water beds of the cretaceous.

Judging from my own experience, we must unquestionably refer this supply of silica to the large fields of deep-sea siliceous sponges, which when dead and decomposed supply the spicules found scattered all through the calcareous mass of the deep-sea globigerina ooze. These siliceous sponges are often found in great numbers, as in the globigerina ooze off Santa Cruz for instance, where numerous specimens of an interesting new Pheronema were dredged, as many as ten to fifteen in a single haul. The whole mass of the mud was so thoroughly impregnated with spicules and with sponge sarcode as to be sticky and viscid. More than once the dredge "must have plunged headlong into one of the ubiquitous sponge-beds, — the glairy mass like white of egg, with a multitude of spicules distributed like hair in mortar throughout the mud." This, as well as the analyses of the bottoms, plainly shows that the amorphous substance, giving to the mud its viscidity, is not produced by sulphate of lime in a flocculent state, but is due to the presence of a mass of decomposed protoplasm, — the remnants of all the animal life which has accumulated for ages upon the bed of the ocean. This is slowly used again by living animals, and kept from putrefaction and decay, by being preserved, in the excess of carbonic

mata contained over 98, and Porites only 95.8 per cent of carbonate of lime. These corals have about two per cent of organic matter, which when fresh gives a strong reaction for phosphoric acid. The remaining one to two per cent is made up of silica, magnesia, fluorine, phosphoric acid, and alumina and iron oxide.

acid, in regions where no rapid oxidation takes place, either from currents, or waves, or from other atmospheric influences.

An immense amount of silica must find its way into the sea, and be immediately dissolved by the excess of carbonic acid found near the bottom, while only a portion of the calcareous mud can be taken up in solution. Hence, this silica is at once placed under the most favorable conditions for resorption by organisms living upon the layer of protoplasmic substance which covers the bottom of the ocean, into which the silica has been received. As Wallich and others have most distinctly proved, this protoplasmic layer, where it exists, is the product of the organic life, and not its source.

Wallich gives some most excellent reasons for supposing that the silex nodules found in the chalk owe their origin to sponges. This is additional evidence in favor of the opinion, which is gradually gaining ground, that the deep-sea calcareous mud is but a chalk deposited in the present epoch, and in every way to be compared with the chalks of the cretaceous period; and further still, that this deposition of chalk has been going on uninterruptedly from cretaceous times, and that we may be said, as far as that special deposit is concerned, to be living in the period of the chalk, for no lithological distinction of any value has been established between the chalk proper and the calcareous mud of the Atlantic.

The Atlantic ooze is mainly made up of the calcareous casts of globigerinæ, and their sarcode must have contributed in no small degree to the protoplasmic mass of the bottom. It must have been an important addition to the silica supplied by sponges in the seas where siliceous foraminifera are abundant.[1] As an additional source of supply of silica we have the extensive deposits of diatoms, which fall to the bottom after death. A similar condition of things probably existed during cretaceous times, and the chalk flints were derived from the same groups of animals which now supply the silica and the globigerina ooze of the Atlantic.

[1] Sir Henry De la Beche states, that siliceous particles are generally disseminated in water if mixed with clayey matter, but if allowed to remain too long in suspension the silex will become aggregated into small lumps.

The absence of typical cretaceous belemnites, baculites, and ammonites does not in the least prove that a process similar to that which deposited the chalk of the cretaceous period may not be going on at the present day on the floor of the Atlantic. But owing to the variable nature of the bottom, it does not follow by any means that the same process is going on synchronously all over the Atlantic bed. Deep-sea muds, such as we find on the steep slopes like those of Hatteras, the Windward Passage, and the continental slopes of the Gulf of Mexico and the Caribbean, can be compared to fossiliferous shales.

How far the presence of deep-water types can be traced to palæozoic times is very uncertain. All the evidence thus far tends to show that the deep-sea fauna originated at the close of the palæozoic times, for many of the genera which we have been led to consider as deep-sea types in the mesozoic period lived in comparatively shallow water. The Lingula of to-day is a shallow-water dweller; it may have been one then. The presence of pteropods and thin-shelled cystideans, and of many blind trilobites, would seem, however, to indicate the existence of invertebrates at considerable depths along the continental slopes even in these early days. Deep-sea faunæ, like all marine faunæ, are essentially dependent upon the nature of the bottom; in former times, globigerinæ and siliceous sponges must have flourished on calcareous ooze; mollusca and annelids characterized muddy bottoms, while polyps, gorgoniæ, and corals throve on rocky ground. It is to be noticed that those of the older formations which were probably deposited in deep water, always appear to be of far greater thickness than the so-called littoral beds. This would show that there was in past times as great a variety of conditions in which marine animals lived as we find at the present day, and that the limits of temperature were fully as great; while the existence of equatorial currents tended to give the marine animals a wider unbroken range than they now have. There were then striking contrasts of temperature between eastern and western continental shores, and variations of a few degrees were quite sufficient to produce very different climates. There are many of the same types in the deep waters of the Atlantic, the Pacific, and the Southern

Oceans, — the survivors perhaps of an abyssal fauna, which, thanks to the distributing agency of the equatorial currents, extended, in mesozoic times, over the whole floor of the equatorial and a part of the temperate zones.[1]

[1] Under favorable conditions, animals having a wide geographical and geological distribution have been found in proximity to continental masses. The "Albatross" has dredged in deep water off Chesapeake Bay many deep-sea types first known from the European tertiaries, from the arctic and antarctic, from the shores of Europe and of South America, from the West Indies, and even from India and the Pacific Ocean.

VIII.

THE DEEP-SEA FAUNA.

It is vain to inquire what animals and plants could have lived in the primordial ocean. We can only conjecture, if we adopt the speculations of Mallet regarding the conditions of the ocean, that they must have been capable of bearing an intense degree of heat, and probably inhabited a mass of boiling mud.

Whole classes of animals and plants live only in the water, and cannot subsist elsewhere: water penetrates all their tissues, and from it they take the elements needed for their growth. Animals living in salt water, with very few exceptions, die in fresh water, probably from the lack of soluble salts.[1] There are vast numbers of animals whose function seems to be the distribution of the soluble salts which have from time immemorial been swept into the sea. Globigerinæ, pteropods, mollusks, echinoderms, corals, and sponges, all distribute over the floor of the ocean, in the form of shells or solid calcareous skeletons, the lime and silica which they have derived from the sea-water.

In an atmosphere saturated with moisture, crustacea could live under moist stones and bark. Lichens as well as many infusoria, which when dry remain inert, but are resuscitated by moisture again, may have formed the principal elements of the fauna, and have survived during the transition from the older marine to a very moist climate, or one resembling the climates of the present day. Similar adaptations may have led to the gradual change of marine shells into terrestrial types. In fishes proper

[1] Sharks are known to inhabit Lake Nicaragua and the fresh waters of some of the larger rivers of India; many marine fishes, selachians, and cetaceans common on the shores of northern Brazil extend far up the Amazons, and some hydroids flourish in fresh water.

the swimming-bladder precedes in time the lung, which first developed among reptiles. The development is from aquatic batrachians to saurians, and finally to warm-blooded vertebrates, adapted mainly to a terrestrial existence.

If, as has been suggested by Moseley, the condition of life of the earliest littoral types was pelagic, we may find in this an explanation of the reversion of the larval forms of so large a number of our littoral species to a pelagic free-swimming stage.

The believer in cataclysms and the man who seeks in natural causes an explanation of the phenomena around him will each put his own reading on all attempts to explain the causes of the apparent revolutions of earlier geological periods. As those revolutions were undoubtedly limited to well defined areas, species living within narrow boundaries in the depths of the ocean may have continued to exist till from local disturbances they in their turn disappeared.

We are justified in explaining the difference between adjoining deposits, the one barren of animal life, the other crowded with animal remains, by supposing conditions similar to those we find in contiguous areas in the depths of the sea. These differences imply variations in the physical conditions of adjoining areas; they are not climatic or necessarily due to geological changes. One area will be teeming with animal life, while the other, either from want of food, from the constant deposition of sediment, or from the sudden changes of temperature affecting it, may be a desert on the surface of which no animal life can maintain itself.

At the time when the greater part of the surface of the earth was covered by water, during the laurentian, huronian, and cambrian periods, the seas contained annelid tracks, sponges, polyps, some echinoderms, and brachiopods, with few marine plants. From these low types, whether they are the earliest or not, must have descended the present population of the seas and land, both animal and vegetable. The study of the currents of early geological periods can to a certain extent give us a clue to the regions from which subsequent marine faunæ have descended, radiating thence little by little over the globe.

On comparing the marine fauna of some of the older formations with that of recent ones, we are struck with the similarity of the types. In the silurian we find crinoids, echini, starfishes, crustacea, mollusca, and fishes, an association of types like those of our epoch. Some groups, however, attained at that early day a preponderance such as none of the types of the present epoch have ever reached.

There is nothing in our living fauna, for instance, analogous to the immense development of the crinoids or of the trilobites, the most prominent crustacea of the silurian period, which disappeared abruptly at the time of the coal period, and are represented to-day only by our horseshoe crabs. The ammonites — which, like their distant allies of to-day, the nautilus, argonaut, and spirula, must have swept over the surface of the seas, or sunk to its greatest depths — have had a most remarkable history. From straight gigantic shells, nearly rivalling in size the huge squid of to-day, they have passed through a series of transformations, including types of the most complicated combinations, and finally seem to have succumbed to the exquisite perfection of their type, and to have been killed in the struggle for life. They were slowly relegated to interior seas, and, ceasing to advance, gradually died out.

The depths of the seas seem at first glance the safest of all retreats, — the secret abysses where the survivors of former geological periods would be sure to be found. Yet oceanic dredgings have not brought to light as many of the ancient types as the more enthusiastic dredgers had led us to expect. They have, however, given us a large number of animals living in deep water, where they have been subjected to no violent changes, to which no revolutions of the surface of the earth can extend, and where the only changes are probably those of temperature, — animals living now in the depths of the sea, under much the same conditions as those which prevailed during the last days of the jurassic period.

The conclusion drawn from these facts by Lovén, Moseley, Perrier, and others is that the abyssal fauna has descended from the littoral and other shallow regions, to be acclimatized at great depths. The conditions of existence becoming more

and more constant, or even in the deeper regions perfectly uniform, species of the most varied derivations, when they had once attained a certain zone, could spread everywhere. This explains at once how the deep-water fauna presents a very uniform composition in all regions of the globe, but at the same time includes various species the analogues of which live in the sublittoral regions of both cold and hot climates, and may have sent an occasional wanderer into deeper waters.

While the little dredging thus far done in deep water has added to our knowledge a large number of antique types which strongly remind us of tertiary, cretaceous, and even of jurassic forms, we should not forget that such antique types occur everywhere, in limited numbers, it is true, both in the shallower regions of the sea and in fresh water. We can only say that in the deep-water fauna a relatively larger number of such antique forms has been found than elsewhere. In contrasting the littoral with the continental and the abyssal faunæ, the last shows a closer affinity to types of a former period than does the fauna living at higher levels, where the descendants of antique types are also met, but have become familiar from their common occurrence. There are in deep waters no ganoids; to-day their representatives are found in the fresh waters of Australia (Ceratodus) and of North America (Lepidosteus). Neither are there any deep-sea graptolites or belemnites.

Old-fashioned animals like Trigonia, Limulus, and Lingula are all from shallow water, as are also Amphioxus and Cestracion. No species of characteristic palæozoic corals have been dredged, and nothing resembling the remarkable crinoids, so abundant in former times. The affinities of the deep-sea types recall to us mesozoic and cainozoic types, such as we find in the chalk and tertiaries. No such old-fashioned animals have been discovered as throw new light on our zoölogical knowledge, although, as Moseley well says, in our deep-sea explorations we obtain for the first time a glimpse of the fauna and flora of nearly three quarters of the earth's surface. Our whole knowledge of the sea bottom has been created within a few years; before that time we knew little of its fauna and flora beyond what is found on a comparatively narrow belt of the coast line.

That none of the palæozoic forms are found in the deep sea seems to indicate, as has been suggested by Moseley, that its first inhabitants date back no farther than the cretaceous period. Of course, there must have been pelagic animals, and foraminifera may have lived at great depths in the track of the currents, but probably no invertebrates of a period older than the jura and chalk existed, or if they did exist they did not wander far from the continental shelf. Their distribution was then, as today, mainly a question of food. The animals of those times lived upon the coast shelf, and while they and their predecessors remained as fossils in the littoral beds of the earlier formations, their successors, belonging either to the same or to allied genera, passed over into the following period.

The littoral belt is perhaps the most important portion of the sea floor, since within its limits the greatest changes of light, heat, and motion occur. To the modifications which under such influences have taken place during past ages, and are still going on, in this limited area, we may attribute the gradual migration of the littoral fauna into the deeper waters, and into the less favored portions of the continental belt and the abyssal region. This succession we see going on around our shores, and in some groups of animals it has been traced with considerable detail. I may take as an example the history of the origin of the West Indian echinid fauna.

The resemblance of the fauna of the Gulf of Mexico and of the Caribbean to that of the Pacific was noticed by writers, even at a time when the materials available for comparison included but little beyond the littoral fauna. From the results of the deep-sea dredgings we have become quite familiar with the extent of this resemblance. In fact, the deep-sea fauna of the Caribbean and of the Gulf of Mexico is far more closely related to that of the Pacific than to that of the Atlantic. Before the cretaceous period the Gulf of Mexico and the Caribbean were undoubtedly in freer communication with the Pacific than with the Atlantic Ocean; so that, notwithstanding the presence of a number of Atlantic types, the characteristic genera were common to the Pacific. Many of the genera have remained unchanged, since the separation of the Atlantic from the Pacific

by the elevation of the Isthmus of Panama and the Mexican Plateau. To these have been added, especially in the West Indian fauna, a number of Atlantic types, which, as long as the Gulf of Mexico and the Caribbean were practically a part of the Pacific, perhaps did not find conditions as suitable to their development as those which have existed ever since they became merely extensions of the equatorial Atlantic district.

In short, to the successive changes brought about in the physical conditions of the Gulf of Mexico and of the Caribbean, we may ascribe in the main the present state of the West Indian fauna, as compared with that of other geographical districts.

This explanation gives us an apparently good reason for the mixed character of the fauna of the West Indian seas, showing us at the same time that, however long a period may have elapsed since this separation took place, it has not been sufficient to effect any radical change in the echinid fauna of the two sides of the Isthmus. The principal differences are due to the immigration of true Atlantic types into the West Indian faunal region during the tertiary and post-tertiary period. But as the physical conditions of the sea in the tropical regions of the Isthmus are so nearly identical, we could not expect from physical causes alone any great differences to arise between the Panamic and West Indian faunæ.

To ascertain the former distribution of the genera of the West Indian echinid fauna, we should trace back as far as possible the origin of these genera. We find a few genera, like Cidaris, Dorocidaris, Porocidaris, and Salenia, which date back to the jurassic period, and in the tertiary had as wide a geographical distribution as at the present day.

Hemipedina, as old as the jura, is found fossil in the tertiary of North America, and has thus far not been dredged outside of the Caribbean fauna. There are no less than ten genera which date from the cretaceous period, and some of them had during the tertiary as extensive a geographical range as they have to-day.

The genera of the earlier tertiary period characterize largely the West Indian fauna. Of these a few extend into the equa-

torial belt of the Atlantic and Indo-Pacific region. Others have an Atlantic and Pacific range; others again only a more or less limited range in the Caribbean, Indian Ocean, and East Indian Archipelago, and with nearly the same distribution as in the tertiary, having died out from the eastern North Atlantic region where they once flourished. A few genera are strictly tropical American, occurring both on the Pacific and Atlantic sides of the continent; but they formerly had a much wider geographical distribution, having once lived in the tertiary of Egypt and Australia.

Some of the clypeastroids date back to the later tertiary, and they are eminently tropical American, occurring on both sides of the continent.

This leaves a number of genera belonging to the families of the Diadematidæ, Ananchytidæ, and Pourtalesiæ, with an extended geographical range in the tropical belt of both the Atlantic and the Pacific oceans, no representatives of which have yet been found fossil. The nearest allies of the Diadematidæ date from the cretaceous, and the others are to-day the representatives of the types of old-fashioned spatangoids which characterized the cretaceous seas.

This analysis shows that the echinid fauna of the West Indian seas of to-day is made up,—(1) of five jurassic genera; (2) of ten genera which go back to the cretaceous period; (3) of twenty-four genera dating from the earlier tertiary period; (4) of only four genera characteristic of the later tertiaries; (5) of seven genera which we may look upon as the representatives of the Ananchytidæ and Infulasteridæ, and of the Pseudodiadematidæ, of the cretaceous period. In all these old-fashioned genera there are species having a cosmopolitan range.

Of the so-called American genera, containing all most closely allied representative species (Agassizia, Moira, Meoma, Macropneustes, Encope, Mellita, Arbacia) which probably flourished in the Central American seas soon after the closing of the Isthmus of Panama, the three spatangoids date back to the cretaceous, the two clypeastroids and two Echinidæ to the later tertiary. The nearest allies of the clypeastroids are found in

the tertiaries of Western France and of Egypt; the above-named West Indian spatangoids and clypeastroids, as well as Cœlopleurus and Macropneustes, disappeared first from the Eastern Atlantic. The past history of the ten West Indian genera already found in the cretaceous, and of the twenty-four genera descending from the earlier tertiary, gives us but slight assistance in determining the mode of their origin in the Caribbean fauna.

It would be most interesting to be able to make a comparison of the deep-sea Panamic fauna with that of the Caribbean, and to ascertain if, in the continental and abyssal regions, at the depths beyond which the effects of motion, of light, and of heat cease to be prominent factors, there is as marked a difference in the representative species as in those of the littoral fauna.

Soon after the end of the cretaceous period the specialization of the Atlantic and Indo-Pacific marine realms began. Before that time the equatorial currents swept nearly uninterruptedly round the globe, and maintained across the Indo-Pacific and Atlantic the conditions which existed in the Western Atlantic before the equatorial currents became deflected by the West India Islands and the northern extremity of South America. If the physical causes we now see at work have, as they have become altered, also modified the fauna of the equatorial belt district then existing, we should naturally expect to notice after a long period of time the changes thus brought about. We are perhaps justified in ascribing to the subdivision of this equatorial belt, into an Indo-Pacific and an Atlantic district, the marked changes perceptible in the character of the fauna as regards the genera which date back to the late cretaceous, and the changes still more marked in the genera which date from the tertiary period.

How far it is possible for us directly to follow these modifications, and to trace the transition of the older fauna into the characteristic West Indian fauna of to-day, is another question. It involves the necessity of tracing back from the triassic and jurassic periods the genera which have appeared in succession; how far this is practicable I have attempted to show on

a former occasion.[1] The present comparison does not extend so far.

Thanks to the researches of Professor Duncan on the fossil corals of the West Indies, we can carry our comparison of the living corals into the tertiary.

The earlier tertiary fossil corals of the West Indies have but little specific affinity with existing species, and there is some difficulty in comparing the two, owing to the varying conditions of preservation in which the fossils are found. This is especially the case in the raised coral beds, which follow the old shore lines, as indicated by the terraces seen at Barbados and many other islands of the Caribbean. These contain a limited number of species of corals generically and specifically identical with the present West Indian coral fauna. According to Duncan the fossil West Indian corals are related on the one side to the coral fauna which flourished in the oölite, and on the other to a fauna, the first appearance of which is uncertain, but which attained its greatest development in the miocene, and is now represented in the Pacific Ocean and its associated seas. In deep water some of the species with Pacific affinities still live.

From the oldest periods the faunæ of successive reefs had few species in common, but genera were most constant and persistent; and it seems clear that physical conditions which are now absolutely essential to the formation of coral reefs existed during the mesozoic and cainozoic periods. The presence of these conditions enables us to rebuild the geography of the past, and to imagine in the time of the trias a succession of larger and smaller islands far from continents or large rivers, but having deep and shallow seas, such as we now find in coral areas. The simplicity of the physical conditions and their continuance from one age to another seem a natural explanation of the uniformity which has evidently prevailed in all coral regions from the earliest times to the present day.

These conditions offer a ready explanation of the more northern extension of the areas of coral reefs, of their disappearance

[1] "Palæontological and Embryological Development," Address at the Boston Meeting (for 1880) of the American Association for the Advancement of Science.

from the European seas, and of their limitation to those regions of the African, Indian, Australian, Pacific, and West Indian seas which most faithfully represent at the present day the conditions which formerly made it possible for coral reefs to thrive so far to the north as the British Islands. At the same time, they give a natural explanation of the cosmopolitan nature of many of the species of older geological periods. I have already referred to this when speaking of the Echini of the two sides of Panama. The history of coral reefs forms one of the most suggestive aids in tracing the persistency of species and types from the earlier geological times. The identity of some of the cainozoic deep-sea corals with those now living at great depths shows us that, with advancing knowledge, the distinctions between the marine fauna of the miocene and pliocene and the fauna of to-day are constantly narrowed.

It becomes evident that a large number of the species now living must have flourished before the important changes in the physical geography which distinguish the present period from the later tertiaries had taken place. We recognize the main outlines of the bathymetrical faunal divisions as clearly as we trace a tropical, a temperate, and an arctic fauna and flora along a mountain slope within the limits of the tropics.[1] They consist of a littoral fauna, all light, motion, and heat; a continental fauna, with superabundance of food and an equable temperature; and a deep-sea fauna, having a cold, unvaried temperature, deriving its food largely from pelagic animals and plants. It is however impossible to determine zones of depths except in the most general way, because representatives of nearly all the principal groups characteristic of the deep sea find their way up to higher levels, and *vice versa.*

The fauna found at great depths in the ocean is peculiar, and appears to contain many species of extensive geographical range, and to be made up of a smaller number of representative species than is common in areas of lesser depth. We lose the geographical limits we are accustomed to find in lesser depths, and

[1] Oersted was perhaps the first to attempt a subdivision of the littoral range of marine animals and plants. The belts he recognized extended but little beyond low-water mark.

meet something analogous to an alpine or arctic fauna and flora spreading over wide oceanic areas below the continental regions, without the breaks of continuity caused in similar land faunæ by isolated mountain chains.

Hexactinellidæ, brachiopods, Pleurotomariæ, Spirulæ, crinoids, deep-sea corals, Echinothuriæ, Ananchytidæ, Pourtalesiæ, Brisingæ, Elasopodiæ, Macruroids, Ophidiidæ, Willemoesiæ, etc., are among the most characteristic deep-sea types.[1]

There is a gradual transition and disappearance of deep-sea types in the continental and littoral zones, just as vegetation at the level of the sea passes to that of mountains, and finally dies out at varying heights at the snow line.

An attempt has been made by Fuchs to prove that the distribution into littoral, continental, and abyssal zones is not a natural one, and that there are but two zones, the littoral and abyssal, the limits of which are well defined, being determined by the depth to which light penetrates. He bases his conclusions on the facts that marine vegetation, which is impossible without light, and on which so large a number of marine animals depend, is limited to a shallow depth; that the coral reefs and banks of mollusca on which another set of animals depend for shelter are also confined to a very moderate depth; and, lastly, that in the tropics the upper limit of the deep-sea fauna is found in depths of ninety to one hundred fathoms. While I do not deny that many ancient types to which attention has not yet been called do occur in shallow depths, and that the upper limit of many of the deep-sea genera extends into the littoral region across the continental zone, yet from my own experiences in dredging at Barbados, along the slope of the Florida Bank, and in the Gulf of Mexico, I may state that a more abundant fauna of sponges, gorgonians, echinoderms, crustacea, mollusks, anne-

[1] Dr. Norman has given a detailed list of the species dredged in the Northern Atlantic on bottom covered by red clay, and another of the fauna known to live at greater depths than one thousand fathoms. (Presidential Address, Tyneside Naturalists' Field Club, May, 1881, Trans. Nat. Hist. Soc. Northumb., Durham, and Newcastle-on-Tyne, VIII., Part I.) In the description of the characteristic deep-sea animals from the West Indies, the Gulf of Mexico, and the east coast of the United States will be found references to the principal types of the Atlantic abyssal fauna.

lids, etc., can hardly be found anywhere, — comprising genera and species which do not seem to have an extreme bathymetrical range, but are limited to a somewhat narrow continental belt, as I have called it.

We should remember that, while temperature and light are important factors in the tropics, the temperature adapted for deep-sea animals comes nearer to the surface than in the temperate zone. It begins at from three hundred to four hundred fathoms. In the temperate zone the same temperature is not found till we reach a depth of six hundred fathoms. In the polar regions we find the deep-sea forms cropping out far nearer the surface than either in the tropics or in the temperate zone. We are not justified in disregarding the effect of temperature because many species can withstand a considerable range, or because the same or a similar fauna occurs in distant localities under different conditions of temperature.

Other causes acting for a long period may have led to the isolation of the fauna, as in the case of enclosed seas, like the Mediterranean, the Red Sea, the Sulu Sea, the Caribbean, and the Gulf of Mexico. Deep-sea forms may gradually have become accustomed to varying temperatures and thus have acquired a greater bathymetrical distribution.

Since the temperature of the sea is nearly the same everywhere in deep water, we have a uniform cosmopolitan fauna, of considerable antiquity, at great depths, corresponding to that of high isolated peaks or mountain chains. They have preserved down to our own time the remnants of a former fauna, which may once have been connected with a fauna at lower levels during an epoch of ice or of lower temperature.

Wallich speaks of the unchecked migrations along the homothermal sea, and, as subsequent explorations show, the great submarine folds, like the Dolphin and Challenger ridges, form no barrier to migration. Except in the case of the Mediterranean and some of the enclosed seas, they do not rise high enough to reach the belts of higher temperature. In the Gulf of Mexico and in the Caribbean (the American Mediterranean), deep-sea forms are found in abundance, extending to upper limits as high as any occurring in the great oceanic basins; this is

owing to the fact that the temperature of the bottom continues upward along the face of the ridges which separate the Caribbean from the Atlantic.

While it cannot be denied that the littoral fauna is largely influenced by the fact that its inhabitants live within the limits of the action of the sun, — that is, in the variable limits of temperature (150 fathoms), — it does not follow that light alone, which perhaps does not penetrate even to one hundred fathoms, is the all-important factor regulating distribution. The action of the waves, of the shore currents, and of the tides, is only felt in that belt, and must exert a powerful influence in modifying the habits of many of the littoral animals and plants.

Species living beyond one hundred fathoms may dwell in total darkness, and be illuminated at times merely by the movements of abyssal fishes through the forests of phosphorescent alcyonarians, and by the feeble light which many of the deep-sea acalephs, echinoderms, and mollusks emit. Perhaps at those depths as beautiful effects may take place as attend the phosphorescence so common in shallow water along a coral reef. The structure of the organs of vision of the deep-water echinoderms, crustacea, polyps, mollusks, and annelids, differs only in a few cases from that of their congeners in shallower regions, to which the direct light of the sun penetrates. Were it not for the phosphorescence, we might almost imagine the deep-sea animals devouring each other without ever having seen their food, and living for ages under conditions subject to but trifling changes, while during the same length of time terrestrial modifications of great importance were taking place.

Many of the deep-sea gasteropods, as well as some of the fishes and crustacea, are blind. They belong generally to the more antique types, and the absence of eyes and the presence of rudimentary organs of sense are compensated by the development both in fishes and crustacea of tactile organs of gigantic size which serve as special organs of sense.[1]

[1] Grimm, in studying the deep-water fauna of the Caspian, noticed that, while several of the crustacea have well-developed organs of sight, at the same depths there were genera in which the eyes are atrophied, and other organs of sense re-

A number of the deep-water species have retained habits of their congeners from shallower waters, which can be of little use to them. Far beyond the limits to which light is supposed to reach, we find sea-urchins and ophiurans buried in the mud, like many of the littoral species. There are quite as many cases of mimicry among the ophiurans, polyps, crustacea, and annelids which cling to corals or polyps, and imitate their coloring, as in the littoral zone, under very dissimilar conditions of existence.

As has been stated before, the deep-sea flora is most limited; the more highly organized marine plants cannot, owing to absence of light, flourish at any considerable depths. Dr. Carpenter dredged corallines in the Mediterranean at a depth of one hundred fathoms, and Dr. Duncan has noticed a parasitic fungus in corals from a depth of one thousand fathoms. He has also found a lowly organized substance, probably a plant, which bores into siliceous spicules.

The American land has occupied from the remote huronian period to the tertiary the same position as at present, the changes being merely those of relative level between land and sea. During all these changes, there never has been a time when the land was not a fit resort for the leading forms of life, and the same is true of the ocean. We may imagine the distribution of land animals to have taken place from the arctic regions, and that they reached Australia, Africa, and South America, and there remained separated. The physical conditions of these regions were perhaps better adapted to the preservation of the types now characterizing them than to the production of new types. So may we imagine that from the Southern Ocean have little by little been sent forth the deep-sea forms which tend constantly to mix with the modified types farther north.

That animal life could have been disseminated from the arctic regions as a centre can readily be conceived if we bear in mind,

ceive a greater development; as in Niphargus, which has well-developed organs of smell and of touch on its antennæ, while in Onesimus, with only rudimentary eyes, organs of touch are developed in its jaws. In Amblyopsis, from the Mammoth Cave, we note the absence of eyes, and the extraordinary development of tactile organs as special organs of sense. In Chologaster, another cave fish, frequenting external waters of a subterranean origin, eyes are present, and tactile organs are also developed.

as has been suggested by Dawson, that there was a time when the arctic regions had a climate similar to that of some of our Southern States, like North and South Carolina, and during six months were subject to the active light and heat of an arctic summer. We may perhaps thus form an idea of the immense growth and development which animal life must then have known.

The deep-sea fauna in the track of oceanic currents was remarkably uniform, and when they changed, new types must have driven out the old ones. To the action of an equatorial current flowing without interruption where the Isthmus of Panama now intervenes, we ascribe the marked generic affinities found to-day in the deep-sea fauna of both sides of that isthmus; this resemblance of the deep-sea types carries us back to the cretaceous period when the equatorial current found its way between the islands of the huge archipelago occupying northern South America, and a part of Central America and southern Mexico.

We cannot fail to be struck with the narrow limits of temperature which characterize most distinct faunal regions, nor can we fail, while speculating on the course of oceanic currents in former geological periods, to note the simple causes which explain satisfactorily the migration of an ancient flora and fauna to totally different realms. We need not seek for cosmic changes, when such a simple cause as the formation of a barrier to deflect an oceanic current explains the disappearance of climatic conditions at any given point, and their reappearance in some other region of the globe.

Since geologists have begun to compare the deposits of past periods with those of the depths of the sea, as we now know them, they have seen how impossible it is to establish from fossils alone the synchronisms of distant beds. The nature of the deposits, the distance from shore, in fact, the geographical and physical conditions of former times, influenced the marine fauna of past ages as much as that of to-day. There is nothing improbable in the synchronism of foraminiferous beds with clay and shale deposits in which lived faunæ having nothing in common, while these beds themselves had a radically different facies.

A careful study of the facies, of the mode of occurrence of deep-sea faunæ, and of the nature of the bottom as developed by recent explorations, will assist us in obtaining a clearer idea of the conditions under which the continental and abyssal deposits of past ages, dependent not only on the depth, but on the character of the bottom, have been made. The existence of the same species at points remote from one another appear to indicate a somewhat uniform fauna in deep water, extending perhaps, with slight modifications, over extensive areas, from the arctic to the antarctic in both the Atlantic and Pacific oceans. Yet the localization of certain species was one of the most characteristic results of the earlier dredging explorations, and extremely rare animals came up in the dredge by hundreds in certain localities.

The thousands of specimens of some of the species of echinoderms, crustacea, polyps, and other invertebrates, which have been dredged from favorable localities, give us an example of the localization of species identical with that found in many fossiliferous beds of former geological periods. The wide geographical distribution of other species has been equally well proved from their occurrence both in the shallow waters of the arctic region and in deep water in more southern latitudes, but of course this distribution is dependent to a great degree upon the character of the bottom.

Some fishes only extend to a depth of five hundred fathoms; others take their greatest development below that belt, and many of them are blind. Below five hundred fathoms we have a large number of Gadoids, Macruroids, Ophidiidæ, and fishes with large eyes, slender bodies, and rudimentary skeletons. Echinoderms live in masses at considerable depths, and form huge banks, containing a great variety of forms, similar to those found in some of the favored localities for fossils in New York and Iowa.

Species of Echinus, of Brissopsis, of Periaster, of Ophioglypha, of Ophiomusium, and of Ophiozona have been brought up in countless numbers in the dredge. Pentacrinus forms today, as it did in the jurassic seas, forests of specimens at a depth of one hundred to one hundred and fifty fathoms. Deep-sea

corals, solitary forms usually, are often dredged in great numbers, and are in striking contrast to the extensive coral reefs of former geological periods, which resemble those of recent times, and must have flourished in shallow water under conditions of temperature analogous to those of the districts in which coral reefs are found to-day.

The Echini characteristic of the shallower littoral districts were formerly, as now, mainly Clypeastridæ, while the Echinidæ, Cidaridæ, Diadematidæ, and Cœlopleuridæ characterized the continental areas, and the Ananchytidæ, Pourtalesiæ, Phormosomæ, and Galeritidæ probably flourished best in deep water.

Lingula may have been from the earliest times a littoral species, while Terebratula and other brachiopods belonged to the continental and abyssal regions. Gasteropods are found in deep water, but are usually of small size. The larger species seem to have lived, as to-day, in comparatively shallow areas, though a few, such as Voluta, Dentalium, and Pleurotomaria, lived in deep water. Of the cephalopods many are pelagic, others littoral, while Nautilus and Spirula are deep-sea types, though Verrill has dredged shells of the pelagic argonaut in deep water. In the older formations the huge cephalopods of these times were abundant in the littoral regions.

Among the crustacea Eryon-like forms predominate in deep waters, and gigantic isopods and Pygnogonidæ are also found at great depths. Accumulations of terrestrial animals and plants driven out to sea by the winds and currents may likewise find their way to deep-sea deposits.

The remains of pelagic animals, often occurring in great numbers, do not always indicate an oceanic deposit, as they may after their death be taken by the winds and currents far from their habitat, and be carried considerable distances by fishes. The shell of Spirula is found on all tropical beaches. We find immense accumulations of pelagic animals, as well as of the dead carcasses of squids, driven ashore in quantities by storms or caught by the tides. The mortality among fishes is often very great; large shoals are hunted to the shore by predatory species and sharks, and our beaches are not unfrequently lined for long distances with fishes which have perished from sudden unknown causes.

On the character of the bottom upon which these animals die will depend the chance of their being preserved, and while the accumulations of dead limestone carcasses may go on indefinitely at a depth of one hundred to one hundred and fifty fathoms, the same mollusks, when thrown upon rocks, or upon a gravelly or sandy beach which is exposed to a greater or less action of the sea, would soon be reduced to an impalpable powder, and be unrecognizable.

The fine muds and ooze deposited at considerable distances from shore form beds admirably adapted for the preservation of the most delicate pelagic or deep-sea types which may happen to become imbedded in them. The coarser sands and pebbles may form a conglomerate, in which the firmer kinds of invertebrates will occasionally be partially preserved.

When the deposition of a deep-sea mud is rapid, the form of the body of fishes and the soft part of mollusks is often retained, but in littoral flats, where large quantities of gas are evolved, and the decomposition of animal matter takes place rapidly, few well-preserved fossils will be found.

IX.

THE PELAGIC FAUNA AND FLORA.

The pelagic fauna is made up of very distinct factors. It contains many animals which pass their whole life as wanderers on or near the surface, — probably within a couple of hundred fathoms, — where they drift helplessly at the mercy of the winds and waves and currents. While there are stretches of the sea along the line of currents, as, for instance, the course of the Gulf Stream, where the pelagic fauna is more abundant than in other marine regions, there seems to be no portion of the sea from which it is totally absent. The pelagic fauna proper includes representatives of all classes of the animal kingdom, though usually these are of smaller size than their allies on or near the continental shores and beaches. The majority of them are noted for the greater or less transparency of their bodies, while their coloring is generally harmonious with that of the surrounding sea. Pale, bluish, and translucent colors characterize the majority of the pelagic animals that live during the day upon the surface of the water. Such are, for instance, the violet or blue tints of the transparent acalephs and siphonophores; those of the Janthina, which its name describes, of the glassy heteropods and pteropods, and of the iridescent ctenophores, which seem, when touched by the sun, like rainbow fragments floating in the water.

The brilliant Sapphirina, the red Daphnia and globigerina, the pinkish or bluish Salpa, are often seen in such masses that they discolor the water for miles, and make the ocean like a sea of milk. By daylight, only the practised eye detects the separate forms which, from their number and delicate texture, melt into each other. But at night the scene changes. The greater number of the pelagic animals are brilliantly phosphorescent;

and when the sea is calm and the circumstances are favorable, these animals are individualized by the greenish, golden, or sil-

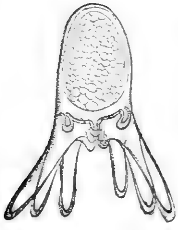


Fig. 63. — Arachnactis, Embryo of Edwardsia. $\frac{10}{1}$.

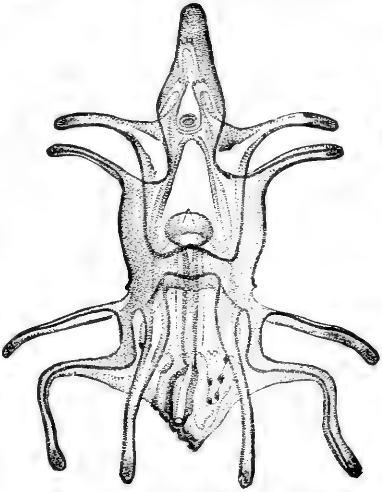


Fig. 64. — Asteracanthion Pluteus. Greatly magnified.

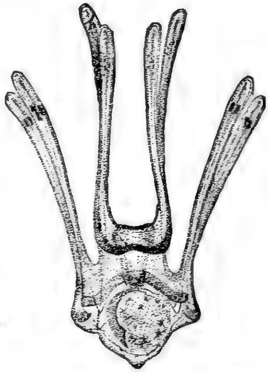


Fig. 64 *a*. — Strongylocentrotus Pluteus. Greatly magnified.

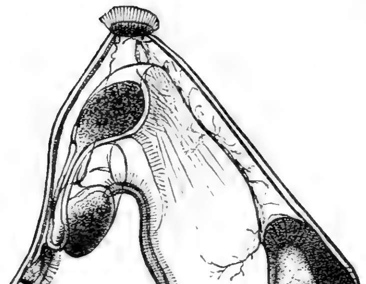


Fig. 65. — Cyphonautes, Embryo of Bryozoön. Greatly magnified.

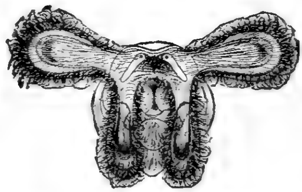


Fig. 66. — Littorina Embryo. $\frac{16}{1}$.

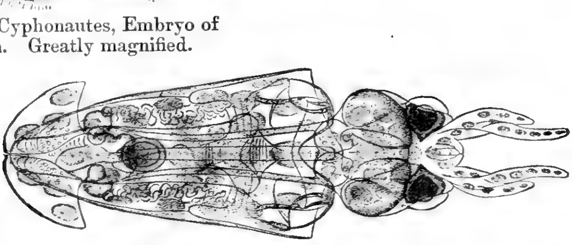


Fig. 67. — Embryo of Loligo. $\frac{20}{1}$.

very light which betrays their presence, and defines their outlines, while it illuminates the sea itself. On tempestuous nights, the phosphorescence, intensified by the motion of the water, adds

singularly to the wildness of the scene. Each wave rises like a mass of molten iron, and seems to threaten the vessel with

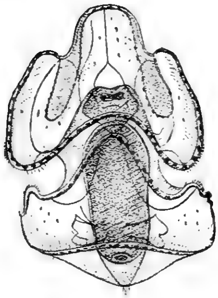


Fig. 68. — Tornaria. Greatly magnified.

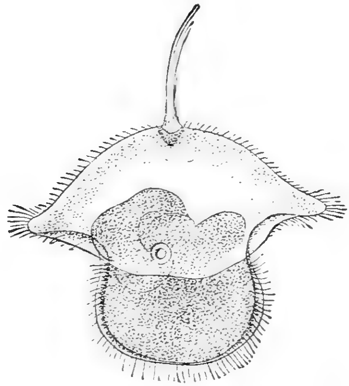


Fig. 69. — Pilidium. Greatly magnified.

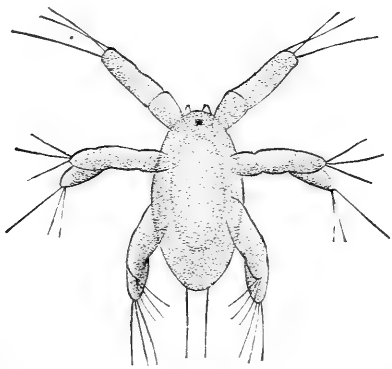


Fig. 72. — Dactylopus Larva. Greatly magnified.

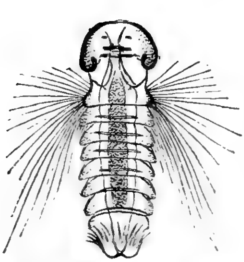


Fig. 70. — Leucodora Larva. Greatly magnified.

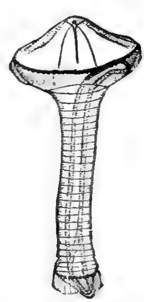


Fig. 71. — Polygordius Larva. $\frac{20}{1}$.

destruction ; it breaks, then passes off in her trail, and adds new beauty to her brilliant wake. In this general illumination,

however, it is easy to distinguish the different forms. The huge ctenophores float by, like luminous balls, among the myriad lesser lights caused by the smaller jelly-fish, while the

Fig. 73. — Balanus Larva. Greatly magnified.

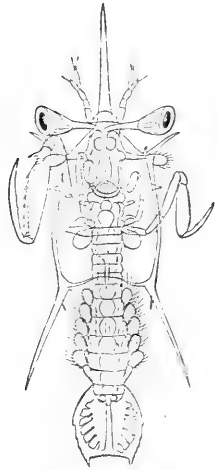


Fig. 74. — Squilla Embryo. $\frac{12}{1}$.

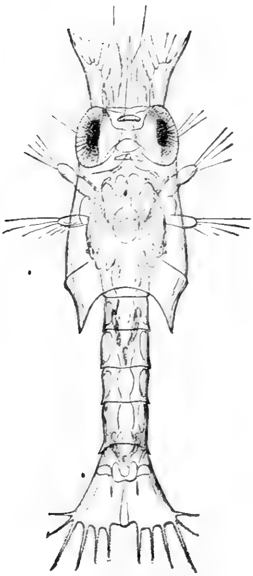


Fig. 75. — Pagurus Larva. Greatly magnified.

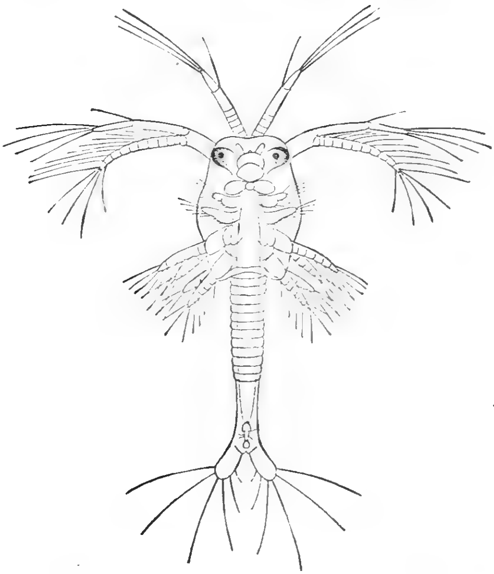


Fig. 76. — Peneus Embryo. Greatly magnified.

Physalia resemble fire-balloons on the surface, and spread the phosphorescence in all directions.

Near the continental lines the pelagic fauna is reinforced by numberless pelagic embryos, representing nearly every type of marine animal. The polyps (Fig. 63), acalephs, echinoderms (Figs. 64, 64*a*), mollusks (Figs. 65, 66, 67), and articulates (Figs. 68, 69, 70, 71, 72, 73, 74, 75, 76), of our coasts, although living upon the bottom and on the shores when adult, yet pass a portion of their earlier life as pelagic forms. The larvæ and young of many of these types swarm during the breeding season, and often find their way to a considerable distance from the shore. With them are associated the eggs (Fig. 77) and embryos of a number of our migratory and shore fishes. The study of all this pelagic life is very recent. There are many types of which the life history is unknown, so that it is often difficult to determine whether an animal is merely the young of some well-known littoral form or a true pelagic type. Indeed, many of these free-swimming animals, described at first as strictly pelagic, have subsequently proved to be only embryonic stages of well-known species.

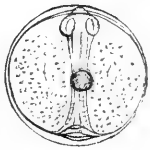


Fig. 77. — Pelagic Fish Egg. $\frac{15}{1}$.

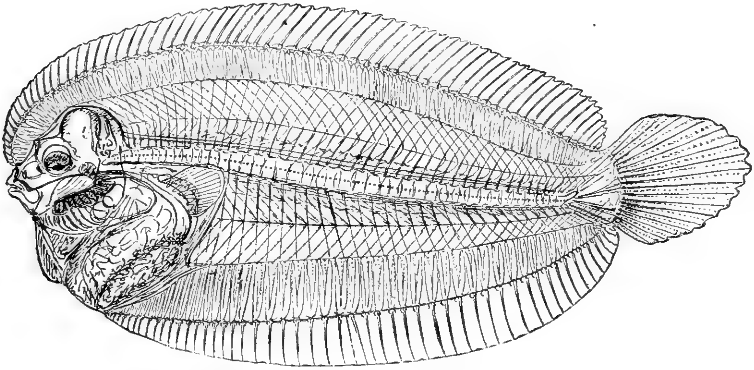


Fig. 78. — Plagusia. $\frac{4}{1}$.

It is probable that among the larval forms of many pelagic animals there is, under certain conditions, a retardation of development similar to that known among batrachians. The larval stage continues in Plagusia (Fig. 78) and Phyllosoma long after the time when the embryo should have passed into Rhombodichthys (Fig. 79) and Palinurus. Leptocephalus is

undoubtedly the larval form of some littoral or deep-sea genus, which, like Amblystoma, has not reached its adult condition, and, if subject to unfavorable influences, continues to increase in size as long as it remains pelagic.

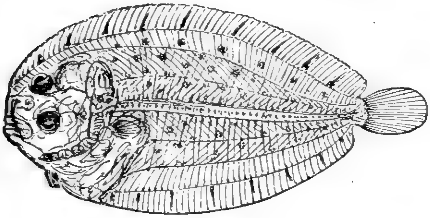


Fig. 79. — Rhombodichthys (Plagusia). $\frac{1}{1}$.

The great development of the organs of sense and of locomotion is a striking feature, which pelagic types share in common with the embryonic stages of many littoral marine animals. It is true not only of the pelagic crustacea and annelids, but even of certain vertebrate embryos, in which the organs of sense are developed out of all proportion to the size of the embryo. Compare, for instance, the size of the eyes, of the brain, and of the dorsal chord, in the young stages (Fig. 80), with their ulti-

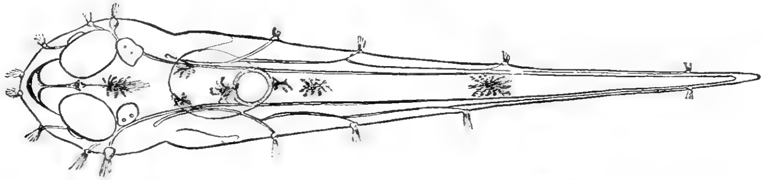


Fig. 80. — Embryo Fish, with Lateral Organs. $\frac{16}{1}$.

mate proportions in the full-grown fish. Or, as another instance, take the Phronima (Fig. 81), which, not satisfied with a set of eyes enabling it to see both laterally and downward, has

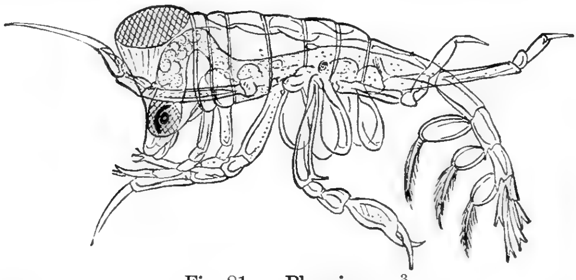


Fig. 81. — Phronima. $\frac{3}{1}$.

also an immense pair facing dorsally, so that the animal has a free field of vision in all directions.

The lateral or cephalic sense-organs of some pelagic fishes

are also sometimes brilliantly phosphorescent. The lateral organs, though they are prominent in the young, disappear or become atrophied in the adult. We can indeed say, with truth, that many of the young fishes, soon after they escape from the egg, are only bundles of nerves, ready to be acted upon by every influence of light, heat, or motion.

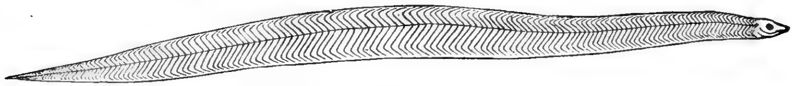


Fig. 82. — Leptocephalus. $\frac{3}{4}$.

The range of vision of a Plagusia, a thin, transparent pelagic flounder, or of Leptocephalus (Fig. 82), a long, narrow, transparent tape-like fish, is very great. In the case of the former, it is really comical to see either eye winking at you through the transparent head. The same disproportion exists between the gigantic eyes of zoeæ and other embryo crustaceans, and those of the adult; nor is the difference less between the size of the organs of sense in embryo acalephs, echinoderms, mollusks, or annelids, and that of the same organs in the adult.

The pelagic animals do not come to the surface at all times. The day fauna is seen at its best only when the sea is smooth and the sun bright. The least ripple on the surface, or the retreat of the sun, is enough to send the more delicate animals into deeper water, beyond the reach of such disturbances. At night again, calm, smooth weather is essential to the many nocturnal animals which come to the surface only in the hours of darkness and disappear with the dawn. It is true, that occasionally a tempestuous night brings out the phosphorescence, but this is rare.

Many of the pelagic animals undoubtedly sink during the day some distance below the surface, in order to escape the intense sunlight. The young of some discophores come to the surface only early in the morning, soon after sunrise.

Some acalephs, like Tima, Zygodactyla, and Staurophora, are very abundant before ten in the morning, while the Polyclonia, (Fig. 83), both old and young, swim about either early in the morning, or late in the afternoon, or during the night; they

generally pass the day resting upon the bottom, with their tentacles turned upwards, the disc pulsating slowly while at rest. The young are far more active than the adult, which, when thus half buried in coral mud, resemble huge actiniæ with fringed tentacular lobes (Phytactis) fully expanded.

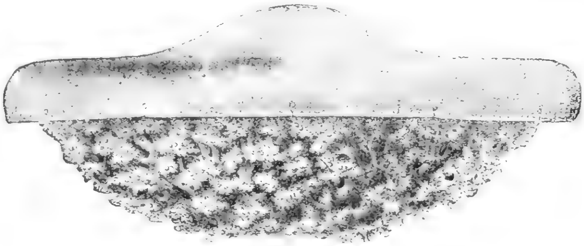


Fig. 83. — Polyclonia frondosa. $\frac{1}{3}$. (Agassiz.)

How far down the pelagic fauna sinks during the day or night to get out of reach of disturbances is not yet accurately known; we can only form a rough guess from the few experiments made on the "Blake," to be found farther on. The lowest point is probably not far from one hundred and fifty fathoms, which is

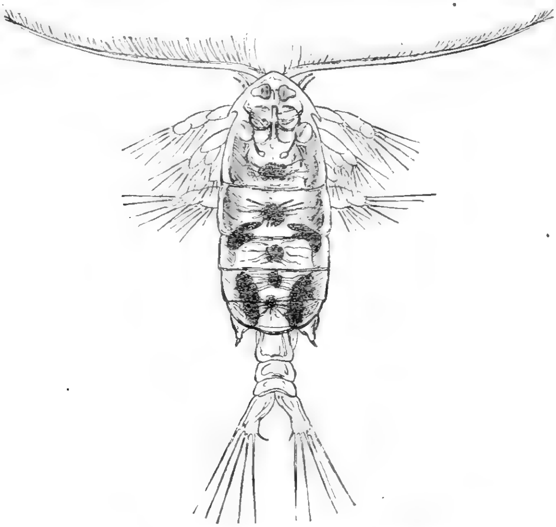


Fig. 84. — Copepod. Greatly magnified.

perhaps the limit also of the greater superficial disturbances of heat, light, and motion within which we may imagine the pelagic fauna to oscillate.

The customary method of collecting these pelagic animals from the surface is by means of a tow-net, dragged behind a boat as it moves slowly through the water, or hung from the sides of the steamer in any weather which allows the handling of a trawl or dredge. The contents of the net are emptied into glass jars, and carefully examined. The larger specimens of fishes, of annelids, of crustaceans, of mollusks, and of cœlenterates, visible to the naked eye, are of course in better condition when collected with a hand-net. The smaller fry alone survive the packing which they get at the bottom of the tow-net. Frequent examination of the net is important in order to obtain in proper condition the more delicate pelagic animals. In many cases the contents of the tow-net consist chiefly of pelagic crustacea, among which the prominent types are the Calani and other pelagic copepods. (Fig. 84.) The many species of Mysis (Fig. 85), regular tramps of the sea, are with the Calani the great marauders of the pelagic fauna, attacking at once any of the larger animals which show the least signs of decay.[1]

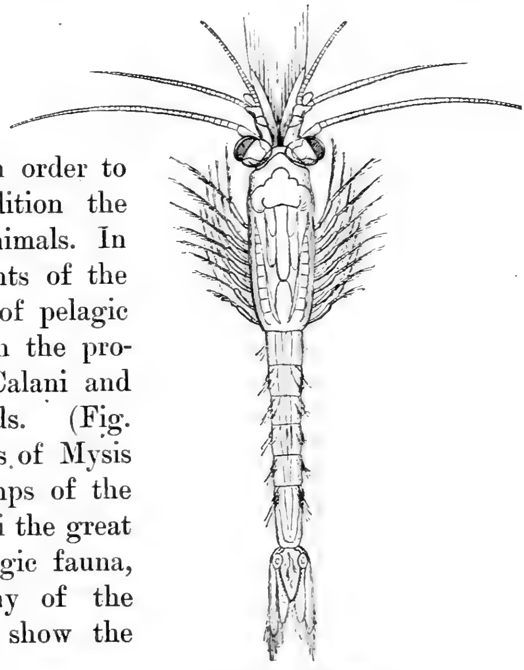


Fig. 85. — Mysis. $\frac{8}{1}$.

[1] Around our coasts and in the Gulf of Mexico and the Caribbean, small Hemiptera (Halobates) (Fig. 123) are not unfrequently met, skimming over the surface at a considerable distance from the coast. The larva of a species of fly (Chironomus) is quite common off shore from our northern coasts. The "Challenger" found the pelagic Halobates very abundant in certain regions of the Pacific.

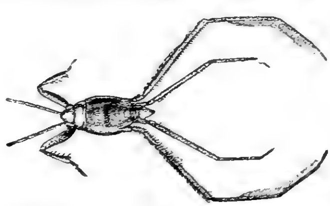


Fig. 123. — Halobates wüllerstorffi. $\frac{8}{1}$. (Chall.)

Eminently characteristic of the Gulf Stream, and wherever its influence extends, Porpitæ (Fig. 86), Velellæ, Physaliæ (Fig. 87), and floating barnacles (Fig. 88) have been found. In

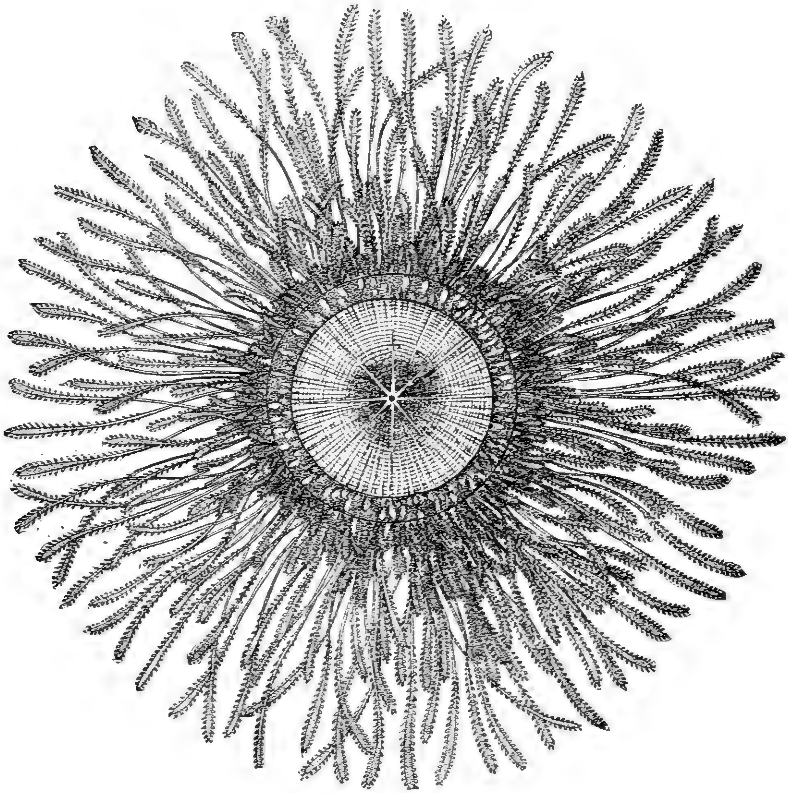


Fig. 86. — Porpita. $\frac{4}{1}$.

fact, these surface animals are excellent guides to the course of the current of the Gulf Stream, — natural current bottles, as it were.[1] They are thrown up along the whole length of the

[1] During the voyage of the "Challenger," observations were made additional to those mentioned by Lyell upon the transportation of seeds by fruit-pigeons; and in the Botany of the "Challenger" Expedition (Chall. Ex., Bot., Part III., p. 277 *et seq.*, 1885), there is an interesting Appendix on the dispersal of plants by oceanic currents and birds. Robert Brown, Chamisso, Darwin, and the French botanists attached to the "Uranie," paid considerable attention to the plants they found scattered on the shores of many of the islands in the Pacific. Moseley describes the masses of driftwood met with by the "Challenger" off New Guinea, about seventy-five miles northeast of Point d'Urville. I have my-

Atlantic coast of the United States, from the Straits of Florida to the south shores of Cape Cod and Nantucket. Physalia, Velella, and Porpita are occasionally driven into Narragansett Bay; the first is an annual visitant, the last has only been found once, in 1875, and Velella has come into Newport harbor during three summers. It is undoubtedly also to the action of the Gulf Stream that we must ascribe the presence of the few species of siphonophores which appear on the southern coast of New England towards the middle and last of September, such as Eudoxia, Epibulia, and Diplophysa, which are found at the Tortugas. Agalma (Fig. 89) and Nanomya, on the con-

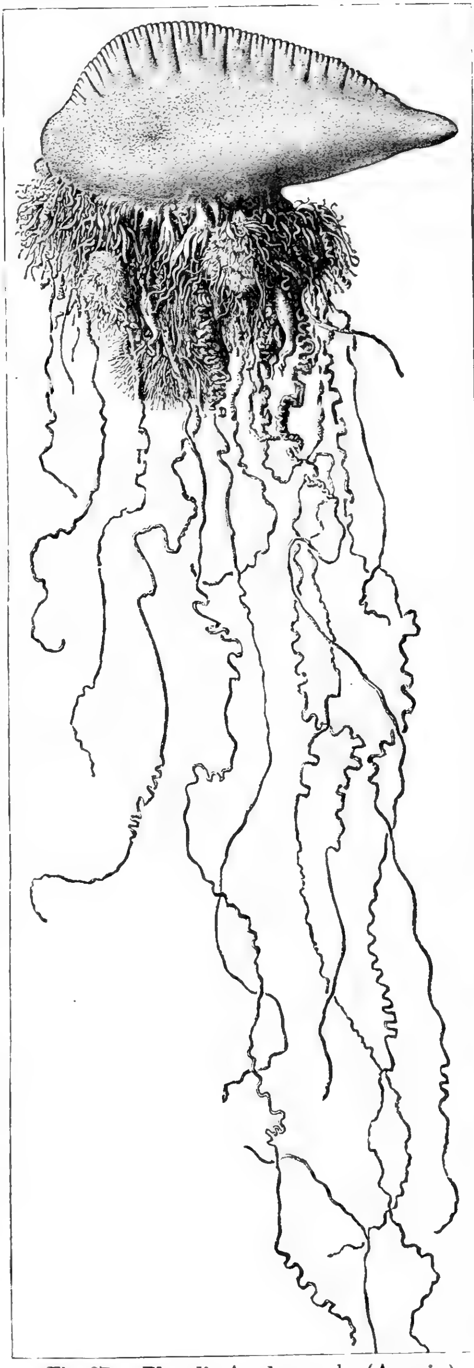


Fig. 87.—Physalia Arethusa. $\frac{1}{3}$. (Agassiz.)

self seen on the weather shores of Mäui masses of huge Oregon pine logs. On some of the Sandwich Islands there are great accumulations of such masses of drift-wood, probably brought from the northwest coast of the United States. Sloane, in 1696, recognized as coming from Jamaica beans and fruits cast upon the shores of the Orkneys.

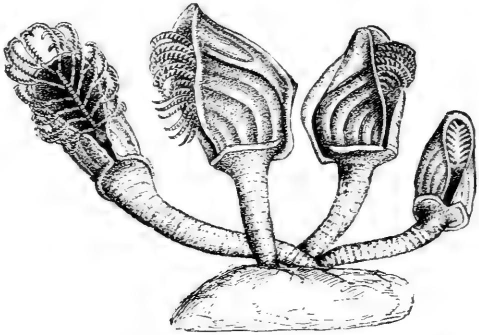


Fig. 88. — Lepas anătifa. Slightly reduced.

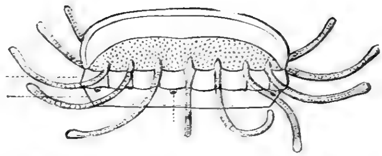


Fig. 90. — Cunina discoides. Magnified.

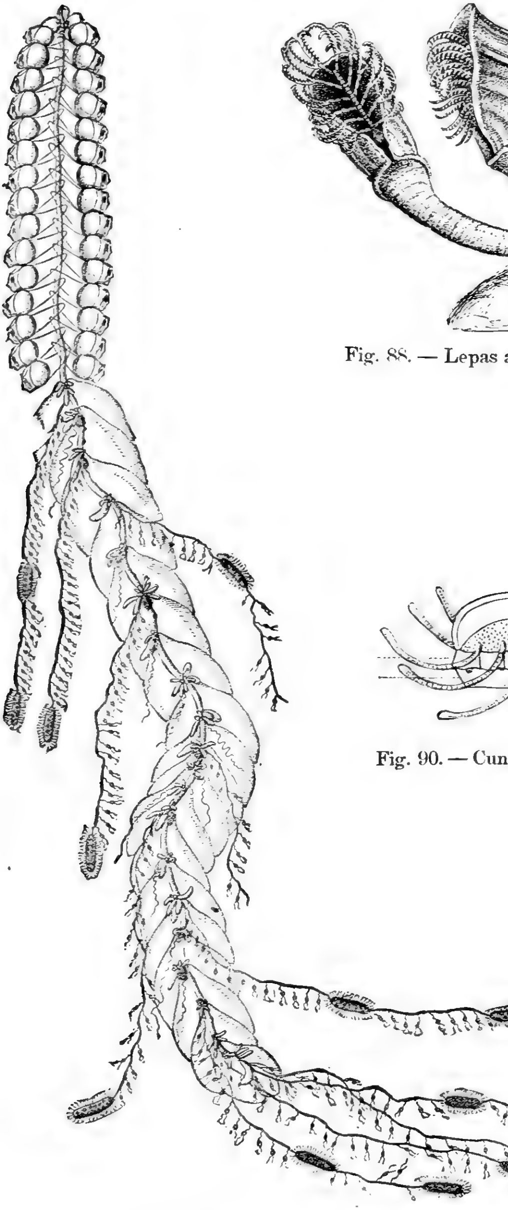


Fig. 89. — Agalma elegans. $\frac{1}{2}$. (Fewkes.)

trary, are northern visitants at Newport, brought down by the arctic shore current from the northern side of Cape Cod, Agalma being common at Eastport. Other species of our southern New

England medusæ, such as Cunina (Fig. 90), Eutima, Trachynema, Eucheilota, Liriope, Zanclea, and many other species which have been described by McCrady from Charleston, S. C., are also brought north every year along the course of the Gulf Stream, and during the summer are blown to the westward towards the New England coast and the Atlantic coast of the Middle States by the prevailing southwesterly winds.

The common green turtle of Florida is caught every year in Narragansett Bay, and the leather-back turtle (Sphargis) has been caught as far north as Massachusetts Bay.

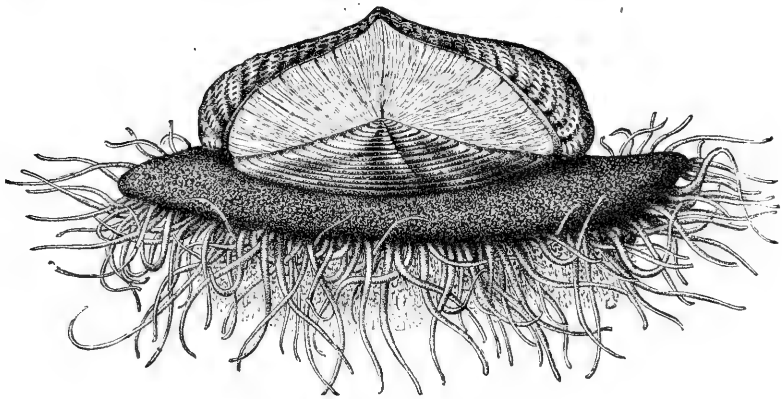


Fig. 91. — Velella mutica. $\frac{3}{4}$.

Velella (Fig. 91) is found in large numbers in the Straits of Florida, between Cuba and the Florida reefs. Thousands of this animal are brought by favorable winds and tides into Key West harbor, and are carried by the same agencies between the Tortugas channels. They are usually seen in large schools, and, although capable in a smooth sea of independent movement by means of their tentacles, are practically at the mercy of the winds and currents. They are destroyed in immense numbers by even moderate waves, which upset them, drive them ashore, or kill them, if kept below the surface for any length of time. They apparently need a good deal of movement, for when kept in confinement they do not thrive, soon die, and are rapidly decomposed. The dead floats are thrown upon the beach behind Fort Jefferson at the Tortugas

in great numbers, forming regular windrows, and, when dry, are blown by the winds to the highest parts of the beach.

Some of the structural features of the Porpitidæ indicate affinities with acalephian corals like the Milleporidæ, which date back to the cretaceous, but their general homologies ally them most closely with the tubularian hydroids of to-day. Among the finest siphonophores is a large Stephanomia, with its bells arranged in many vertical rows.

One of the most interesting siphonophores is *Pterophysa grandis.* (Fig. 92.) Of this species, which grows to a large size, huge specimens measuring no less than thirty feet, often came up on our dredge-wire in the Gulf of Mexico and the Caribbean. It is closely allied to those which Studer, the naturalist of the "Gazelle," regards as strictly deep-sea siphonophores. The polypite of large specimens often measured two to three inches.

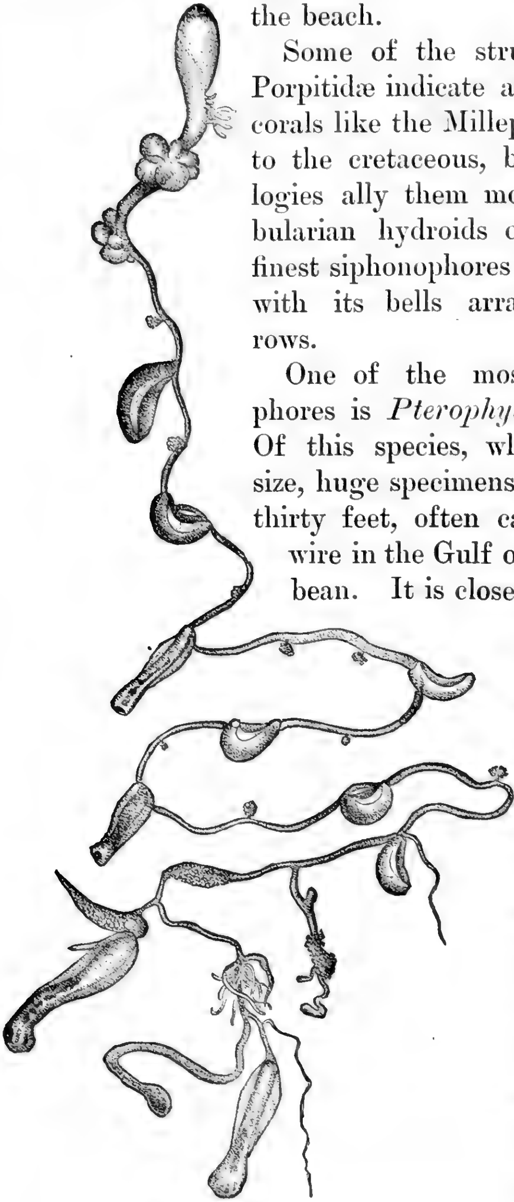


Fig. 92.—Pterophysa grandis. $\frac{1}{12}$. (Fewkes.)

Pterophysa and other siphonophores have the power of sinking and then swimming back to the surface, but neither Velella nor Porpita appears capable of such movements. A very young Physalia, collected at the Tortugas, was observed to swim at different levels in the jar in which it was kept.

Studer gives a list of the depths from which Rhizophysa came up attached to the sounding-line; but it is by no means certain that these siphonophores belonged in the depths indicated by the wire. They may have become caught on the wire while it was reeling in at only a short distance from the surface.[1] The fact that Studer never succeeded in bringing up any of these species in the tow-net, even when it was lowered to a considerable depth, is equally inconclusive, since, at any rate in the Caribbean Sea, their isolated parts and fragments are not infrequently found floating on the surface. It is probable that they usually live at a constant depth below the surface, and some of them may, like Polyclonia, prefer to dwell near the bottom. But until we possess a net so constructed as to give some sure indication of the intermediate depths at which the animals living at various distances between the surface and bottom have been gathered in, it seems hazardous to define the bathymetrical range of a large number of pelagic animals, such as the acalephs, siphonophores, heteropods, pteropods, numerous foraminifera, radiolaria, and the like, the habits of which are scarcely known.

In the case of fishes, dredged in deep water at a moderate distance from the land, we ought not to take it for granted that they invariaby live at the depth to which the trawl may have been lowered. The young of many of the deep-water fishes are undoubtedly pelagic, often till a late period of growth, and this would account for the discovery of many of the deep-water fishes, especially in the proximity of oceanic islands or around coasts situated near deep water.

Of the acalephs, the greater number of the ctenophores, many of the discophores and a few sertularians, are pelagic; the majority of the hydroids and some of the discophores are pelagic only during a period of their existence, and remain the rest of the time attached to the bottom; as fixed hydroids, they extend into deep water. A number of families of discophores are

[1] In one case, when we were dredging in one thousand fathoms, numerous fragments of a Rhizophysa came up after we had drawn in one hundred fathoms of wire! On another occasion, the same species came up after we had drawn in three hundred fathoms, while dredging in five hundred fathoms.

characteristic inhabitants of deep water, though they come to the surface occasionally.

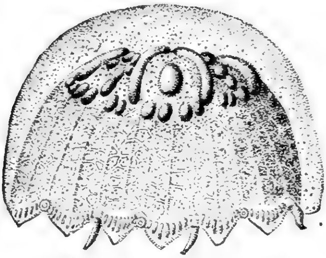


Fig. 93. — Linerges mercurius. $\frac{2}{1}$.

Nearly all the ctenophores are found in swarms, which cover the surface for long distances. Schools of discophores are not uncommon. I have frequently met Cyaneæ and Aureliæ in such quantities that they appeared at a distance like huge sand-banks, just rising to the surface of the water.

Occurring in windrows along the whole length of the Florida Reef is a small yellowish brown discophore (Fig. 93) (*Linerges*

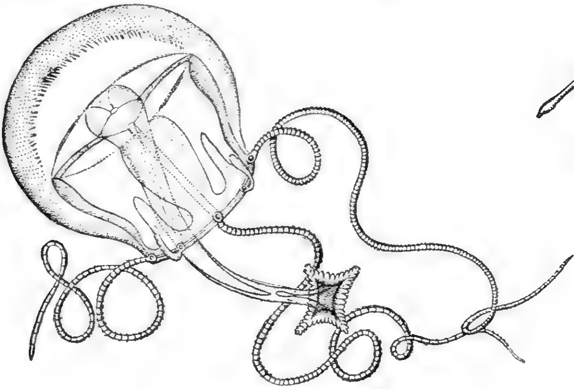


Fig. 94. — Glossocodon tenuirostris. Magnified.

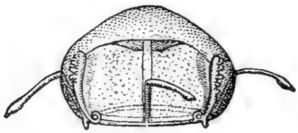


Fig. 95. — Fourth Stage. Glossocodon Larva. Greatly magnified.

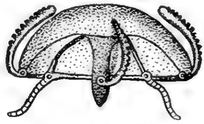


Fig. 96. — Sixth Stage. Glossocodon Larva. Greatly magnified.

mercurius), which looks like a thimble ; it is one of the most common of the West Indian medusæ, and is remarkable for the

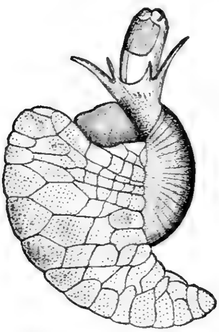


Fig. 97. — Janthina. Slightly reduced.

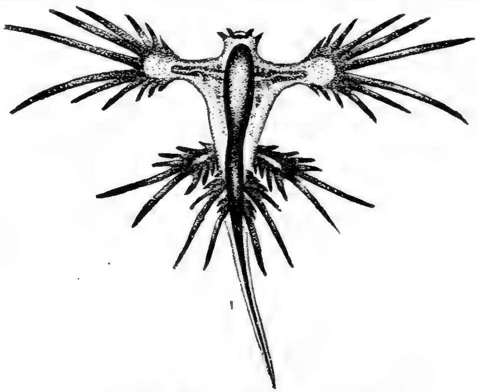


Fig. 98. — Glaucus. Enlarged.

pouches, bag-like expansions of the lower floor of the bell, which hang down into the bell cavity. Among the more interesting hydroids may also be mentioned a species of Glossocodon (Fig. 94), noticeable for the changes it undergoes during growth. (Figs. 95, 96.)

Of the surface mollusks of the Gulf Stream, Janthina (Fig. 97) is very common, and is often seen in large numbers, helplessly carried along by the current with the dark blue Glaucus. (Fig. 98.) During the day an occasional pteropod is seen; but at night no cast of the tow-net is made without

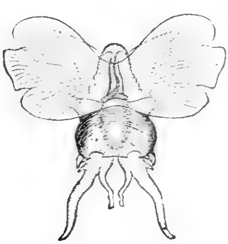


Fig. 99. Hyalea. $\frac{2}{1}$.

Fig. 100. — Atlanta. $\frac{10}{1}$.

bringing them up in numbers. Characteristic of the Gulf Stream are Hyalea (Fig. 99), which, like the more common Atlanta (Fig. 100), Styliola (Fig. 101), Pleuropus (Fig. 102), and Tiedemannia (Fig. 103), find their way far north to the shores of Narragansett Bay and southern New England; while among the more common types of the Straits of Florida and of the Gulf of Mexico are Salpa, Doliolum (Figs. 104–106), Pyrosoma (Fig. 107), and Appendicularia (Figs. 108, 109), all belonging to types of which individuals collect frequently in such numbers as to fill the ocean as far as the eye can penetrate, reaching out for miles in all directions. Salpæ, as has been shown by Moseley, sink rapidly to the bottom (two thousand fathoms in two days) where they die; and their dead bodies, as well as the mass of dead pteropods, heteropods, crus-

tacea, and foraminifera, must form an important element in

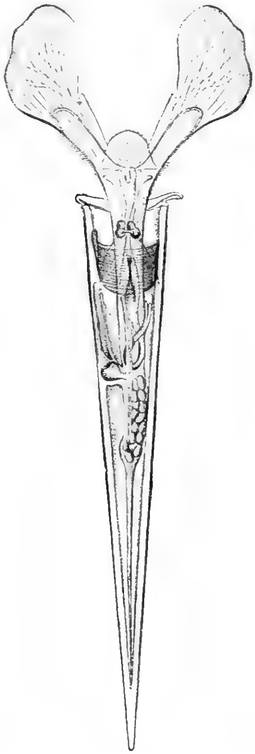


Fig. 101. — Styliola. $\frac{5}{1}$.

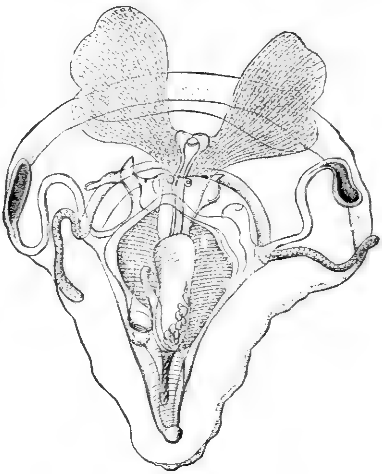


Fig. 102. — Pleuropus. $\frac{10}{1}$.

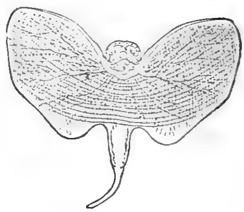


Fig. 103. — Tiedemannia. $\frac{7}{1}$.

the food of the sedentary deep-sea species, as they must reach the bottom long before they are decomposed

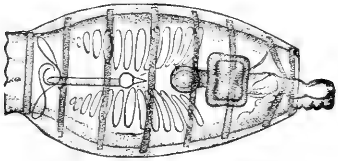


Fig. 104. — Doliolum. $\frac{10}{1}$.

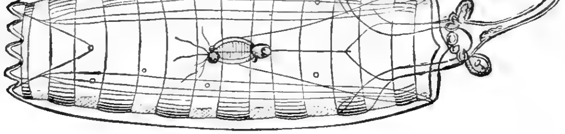


Fig. 105. — Doliolum. $\frac{5}{1}$.

Among the tunicates I may mention two new species of Salpæ, one of which is interesting, since its chain occupies an

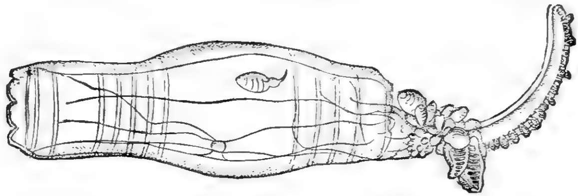


Fig. 106. — Doliolum. $\frac{6}{1}$.

intermediate position between that of *Salpa pinnata* and the ordinary Salpa chain of *S. zonaria* or *S. Caboti* of our coast.

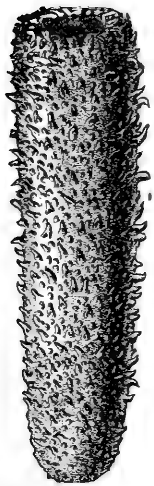


Fig. 107. — Pyrosoma. $\frac{1}{2}$.

Fig. 108. — Appendicularia. Greatly magnified.

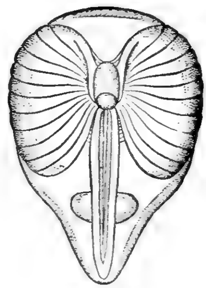


Fig. 109. — Appendicularia House. Greatly magnified.

The solitary individuals are gigantic specimens, measuring no less than twelve inches in length. This solitary form is closely allied to *S. maxima*, but differs from it in the number and arrangement of the muscular bands. The chains grow to a great length, some of them measuring more than ten feet and

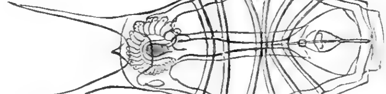


Fig. 110. — Salpa Caboti. Solitary Form. $\frac{2.5}{1}$.

as much as nine inches in breadth. The zoöids are placed as

in *S. pinnata*, side by side in a single row, stretching vertically across the whole width of the chain, and forming a thin ribbon, which when floating is usually slightly coiled like a tape. The zoöids of the chain resemble *S. Africana.* This species was found from Cape Hatteras as far north as the eastern extremity of George's Shoal.

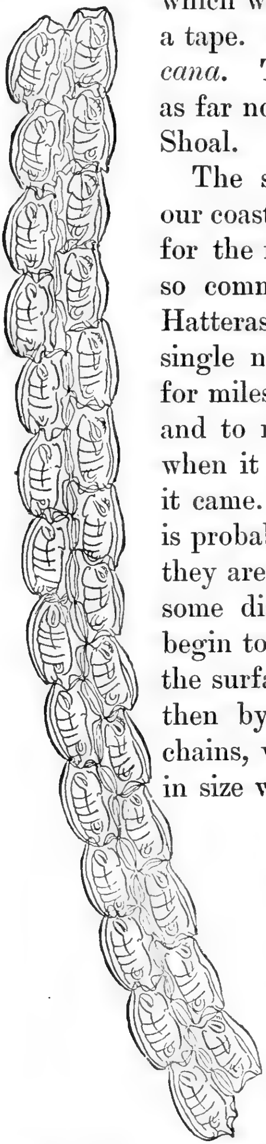


Fig. 111. — Salpa Caboti. Chain, somewhat enlarged.

The sudden arrival of innumerable Salpæ on our coast is most interesting. It is not unfrequent for the northern species of Salpa (Figs. 110, 111), so common along the eastern coast from Cape Hatteras to Cape Cod, to make its appearance in a single night in such masses as to discolor the sea for miles near the entrance of Narragansett Bay, and to remain swarming for a couple of months, when it disappears as quickly and mysteriously as it came. The explanation of this sudden inroad is probably due to the fact, that during the time they are sterile the solitary individuals remain at some distance below the surface, but when they begin to bud and form the chains they come near the surface. It is easy to explain their abundance then by the rapid development of the young chains, which are formed, thrown off, and increase in size with extraordinary rapidity.

The pteropods and heteropods are by far the most common pelagic forms of the mollusca, the dead tests of the former being literally heaped up in beds on the bottom of the sea in deep water. The dredge often came up completely choked with pteropod shells, showing what an important part they play in building up the deep-sea deposits by the decomposition of their tests. In former geological periods, when there were gasteropods allied to pteropods like Bellerophon, of gigantic size, their effect in forming bottom accumulations must have been still

greater. Indeed, if their habits were similar to those of like animals at the present day, they must have supplied a large part of the animal food of deep-sea forms. The heteropods are represented by abundant specimens of Firoloidea (Fig. 112), many fully sixteen inches long, associated with Pterotrachea; Carinaria is also frequently seen.

We know only enough of the habits of our cephalopods to be able to state that some of the species, like Stenoteuthis,

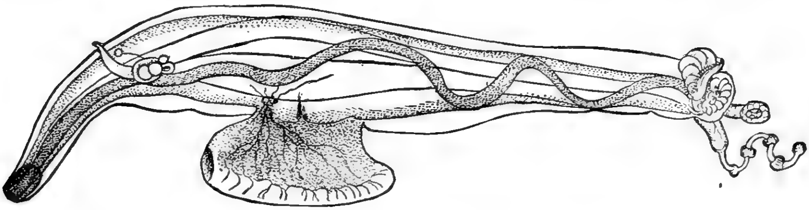


Fig. 112. — Firoloidea. $\frac{1}{2}$.

Stauroteuthis, and the giant squids of Newfoundland, are undoubtedly pelagic at times, although the majority of the species known to come from our coast have been dredged from considerable depths. Many of the cephalopods have great

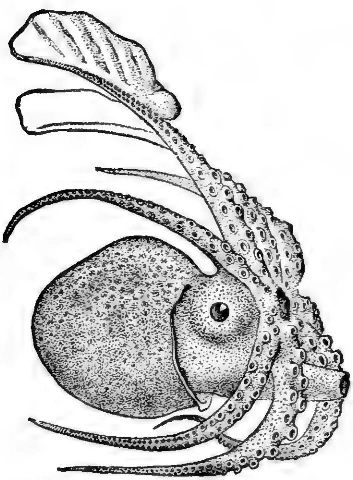


Fig. 113. — Argonauta. $\frac{2}{3}$. (Verrill.)

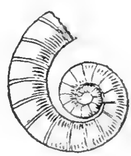


Fig. 114. — Spirula Peronii. $\frac{1}{1}$.

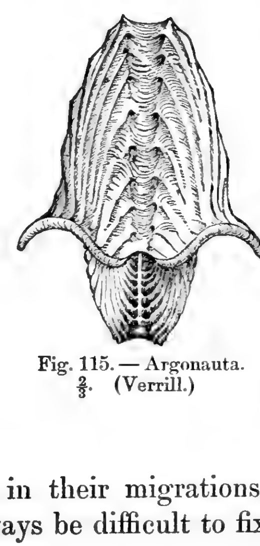


Fig. 115. — Argonauta. $\frac{2}{3}$. (Verrill.)

freedom of locomotion, and equal fishes in their migrations, often moving in schools. But it will always be difficult to fix

the bathymetrical range of free-swimming animals like these. Argonauta (Fig. 113) has been known for a long time to be

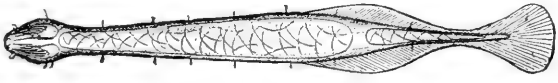


Fig. 116. — Sagitta. $\frac{1}{2}$.

pelagic, while nautilus, though seen at the surface occasionally, is probably a deep-sea type. Spirula has been dredged from deep water by the "Challenger" and "Blake," while French

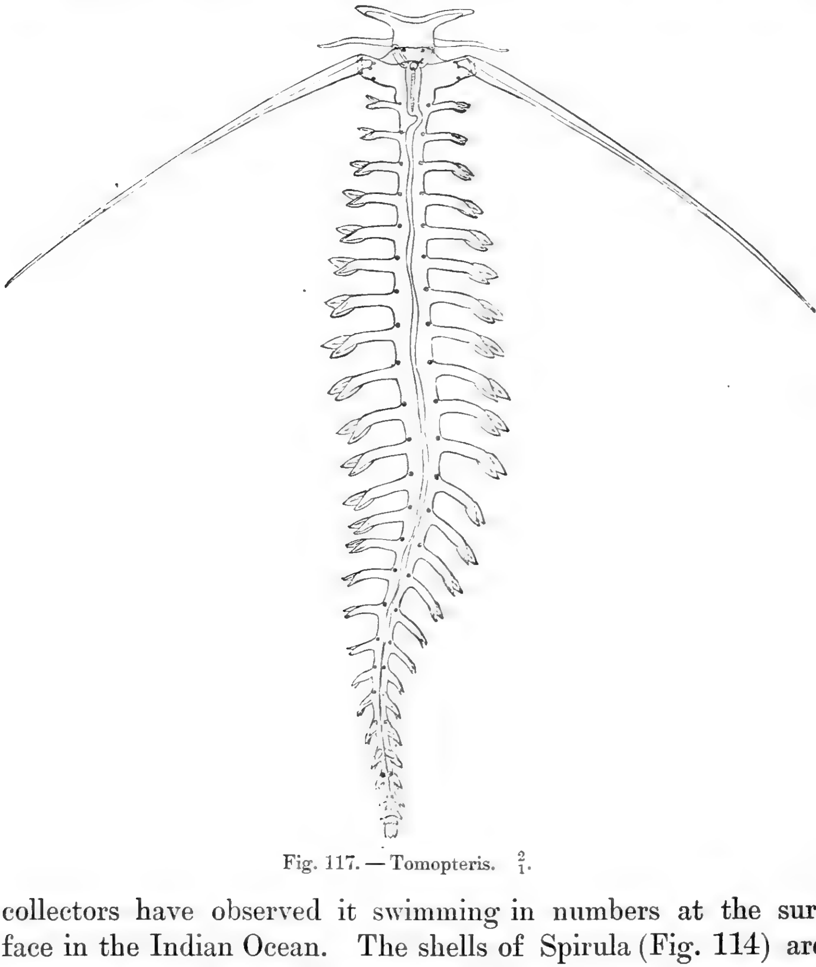


Fig. 117. — Tomopteris. $\frac{2}{1}$.

collectors have observed it swimming in numbers at the surface in the Indian Ocean. The shells of Spirula (Fig. 114) are common on all tropical shores, while the shells of Argonauta

(Fig. 115), though not uncommon in deep waters, are more rarely thrown up on beaches. Professor Giglioli has dredged them in the Mediterranean, and they have been dredged east of Long Island by the United States Fish Commission.

One of the most characteristic of the Atlantic pelagic types is Sagitta (Fig. 116); as its name implies, it darts through the water in search of its minute prey, which it seizes with its gigantic jaws. Other worms, like Autolytus and Nereis, are at times pelagic, while the large-eyed Argyope and the transparent Tomopteris (Fig. 117) are constant attendants of the surface fauna. Of crustacea there are a host of minute predatory forms, — Calanus, Mysis, Nebalia (Fig. 118), etc., — regular scavengers of the surface, and thousands of copepods, the main object of whose existence seems to be to keep themselves on hand as food for the larger pelagic types of crustacea, like Euphausia and its allies. We have certain forms of pelagic fishes, the transparent Plagusiæ, Leptocephali, and the like, some species of which are only the young of deep-sea forms. Pelagic species of fishes often attain a large size, such as the thunny, horse-mackerel, sword-fish, Orthagoriscus, Coryphæna, Histriophorus, and others. The group of flying-fishes is a true pelagic type, to which we might add some of the migratory fishes, as the clupeoids and scombroids. Many of the large types of sharks like the thrasher, basking shark, and mackerel shark, are pelagic, and are met with at great distances from the coast. The skates, on the contrary, are nearly all deep-water types, though they are occasionally seen hunting near the surface. Finally, of the mammals, the whales, dolphins, and porpoises, dancing attendance on ships far out at sea, complete our general enumeration of the pelagic types.

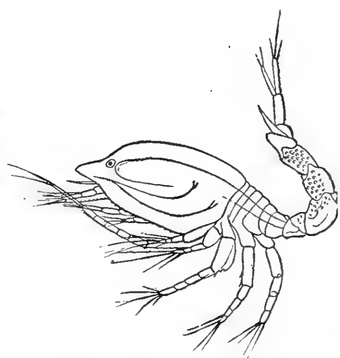


Fig. 118. — Nebalia. $\frac{4}{1}$.

Among the more minute types are the graceful globigerinæ, with their delicate arms, appearing like scarlet dots on the surface of the sea. These swarm on warm, calm days. I had an

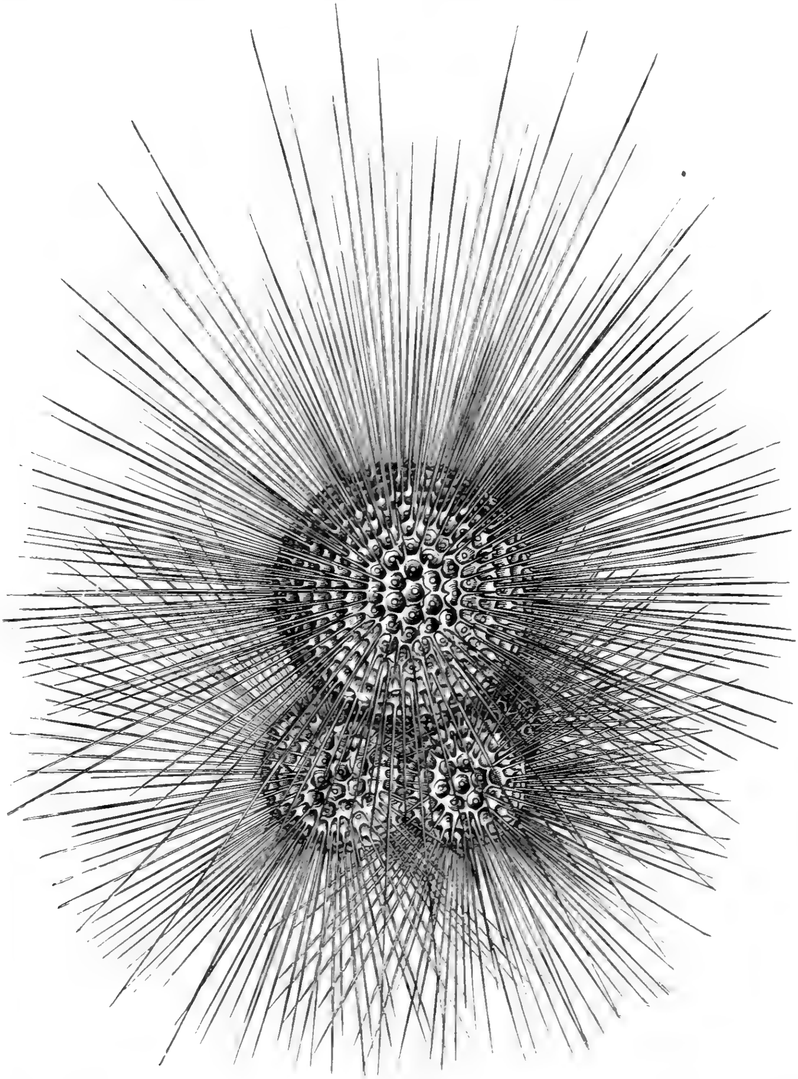


Fig. 119. — Globigerina bulloides. $\frac{150}{1}$. (Challenger.)

excellent opportunity of seeing a number of Globigerinæ (Fig. 119) and Orbulinæ[1] alive on one occasion to the westward of

[1] The genetic connection, if there be any, between Orbulina and Globigerina, which are always found associated together, is not known. It may be a case of dimorphism. See chapter on Rhizopods, vol. ii.

the Tortugas, where numerous patches of them gave a reddish color to the sea.

The siliceous types of Polycistinæ (Fig. 120), so common in former geological times in the West Indies, form an extensive deposit at the Barbados,[1] near the highest part of the island, are now found but rarely in the Atlantic. A few types of the

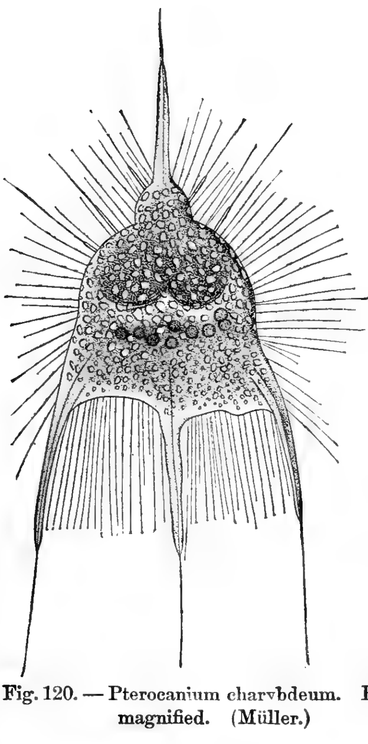


Fig. 120. — Pterocanium charybdeum. Highly magnified. (Müller.)

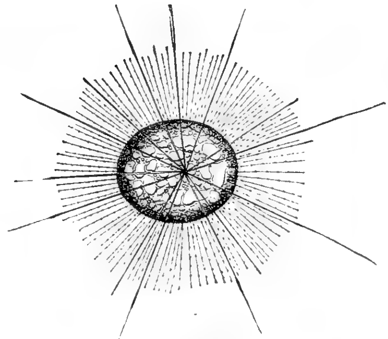


Fig. 121. — Hialomma. $\frac{25}{1}$.

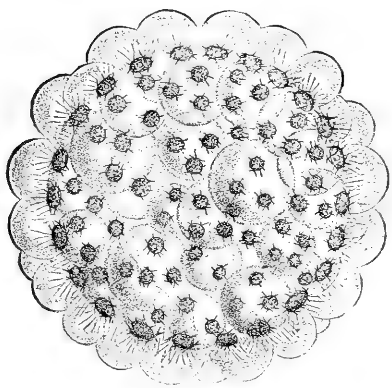


Fig. 122. — Sphærozoum. $\frac{12}{1}$.

Thalassicolæ (Fig. 121), and Acanthometridæ, as well as of such forms as Collozoum and Sphærozoum (Fig. 122), are, however, quite common in the Gulf of Mexico and Caribbean, and during the summer come as far north as the larger pelagic animals. Siliceous radiolarians are quite common in the tropical regions of the Pacific.

While many of the foraminifera, like Globigerina and Has-

[1] Nummulitic beds occur in Thibet at a height of sixteen thousand feet.

tigerina (Fig. 124), are pelagic, there is a host of other arenaceous forms, perhaps the majority of the foraminifera, which certainly live at the bottom. Both the pelagic and bottom species form a most important factor in the food supply of the abyssal fauna. The modern greensand found along the edge of the Gulf Stream proves that multitudes of dead tests constantly drop from the surface, and when they reach bottom, they still contain a sufficient amount of sarcode to make an excellent meal for some abyssal echinoderms. The species that live on the bottom, and in some localities must thickly cover its surface, afford excellent feeding-grounds for the dwellers of these depths. With the thousands of radiolarians and other pelagic globigerinæ occur minute protozoa, their capacity for floating being increased by the huge spines or extensile pseudopodia which they stretch out in every direction. The depth at which so-called pelagic foraminifera have been found depends upon the fact that, during rough weather or under unsuitable circumstances, they sink to a considerable depth, and, while they would strictly come within the definition of pelagic animals, they may thus frequently be found living apparently on the bottom.

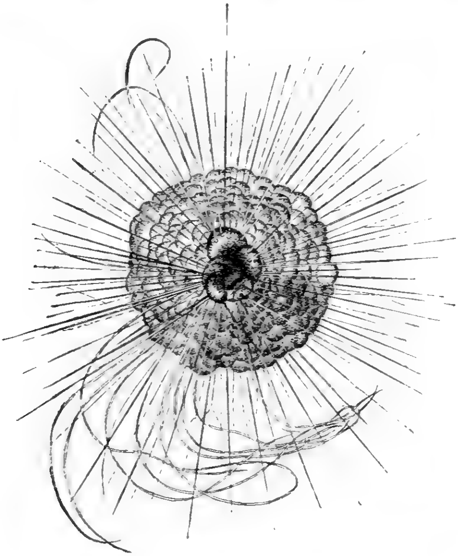


Fig. 124. — Hastigerina pelagica. $\frac{35}{1}$. (Challenger.)

One of the most common of the pelagic protozoa is a species of the genus Noctiluca. (Fig. 125.) On favorable nights it forms a thin sheet of phosphorescence, as it were, spread over the sea. The tow-net, when dragged during the night, reveals the phosphorescent color characteristic of different groups, and one who is accustomed to such nocturnal pelagic

fishing soon learns to know what kind of harvest his night's fishing will give him from the coloring of the phosphorescence he sees passing into his net.

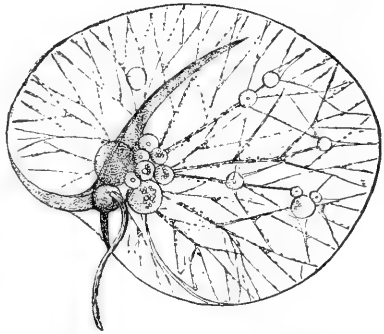


Fig. 125. — Noctiluca. Magnified.

As we lift our net from the water, heavy rills of molten metal seem to flow down its sides, and collect in a glowing mass at the bottom. The jelly-fishes, sparkling and brilliant in the sunshine, have a still lovelier light of their own at night. They send out a greenish golden light, as lustrous as that of the brightest glow-worm, and on a calm summer night the water, if you but dip your hand into it, breaks into shining drops beneath your touch. It would seem that the term "rills of molten metal" could hardly apply to anything so impalpable as a jelly-fish (Figs. 126, 127), but their gelatinous discs give them

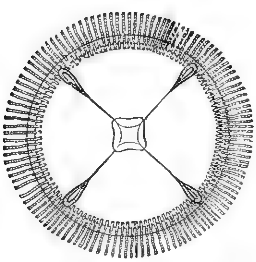


Fig. 126. — Eucope diaphana. $\frac{8}{1}$.

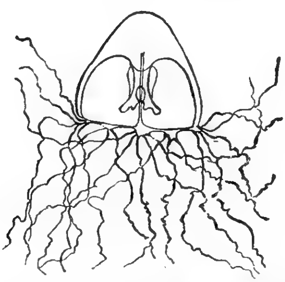


Fig. 127. — Lizzia grata. Magnified.

weight and substance, and when their transparency is not perceived, and their whole mass is aglow with phosphorescent light, they have an appearance of solidity which is most striking when they are lifted out of the water and flow down the sides of the net. The larger acalephs bring with them a dim spreading halo of light, and look like pale phantoms wandering about far below the surface; the smaller ctenophores become little shining spheres, while a thousand lesser creatures add their tiny lamps to the illumination of the ocean.

All this phosphorescence is seen to greatest advantage on a

dark night, when the motion of the vessel sets the sea on fire around one. At such times there is something wild and weird in the whole scene, which at once fascinates and appalls the imagination; one seems to be rocking above a volcano, for the sea is intensely black, except where fitful flashes or broad waves of light break from the water under the motion of the vessel. The sea may be black as ink, with the crests of the waves breaking heavily and surrounding one with walls of fire in all directions.

To Professor Panceri we owe the fullest investigations as yet made into the causes of marine phosphorescence. The phosphorescence is limited to portions of the exterior of the animal; or is connected with special organs, — sometimes with the generative organs; or it may take place wherever tissues change rapidly. But as this power of emitting phosphorescence seems to be always produced by an external irritation, it may be, as has been suggested by Studer, that the phosphorescence serves as a protection for the animal.

The Pyrosomæ, which form so essential a feature in the phosphorescence of the Indian Ocean, are not common in the Caribbean or Gulf of Mexico. The specimens we saw in the track of the "Blake" were diminutive in comparison with those huge fire cylinders, often more than a foot in length, described by naturalists who have sailed through the Indian seas. On the other hand, we found a Salpa colony far exceeding in size those before known, — a huge band, several yards in length and a foot in breadth, which at night, when seen from the deck, seemed like a huge veil of bright greenish phosphorescence. One of the smaller kinds of Salpæ gives out generally a bluish light.

The pelagic fauna of the Eastern Caribbean is, during the winter season, rather scanty. Owing to the constant agitation of the water, I had no opportunity, as in the Gulf of Mexico, of making much use of the tow-net. From the number of fragments constantly found, siphonophores must be very numerous. In the roadstead under the lee of the islands there is little pelagic life. Everything either remains at a short distance below the surface, or is blown away to seaward of the

islands. The phosphorescence, in consequence, is far less brilliant than in the Gulf of Mexico, although occasionally masses of ctenophores (a species of Mnemiopsis) (Fig. 128), swimming at different depths, produce a very striking illumination; sudden flashes of light appear, as if from great balls of fire floating a short distance below the surface. The most surprising phosphorescent phenomena were produced by a small annelid allied to Syllis which we found in Petite Baie d'Arlet. Just after dark, the bay was covered for a time with hundreds of phosphorescent spots gliding slowly about, when suddenly a number of them began to move actively, performing the most remarkable gyrations. Soon the whole bay was traversed by brilliant phosphorescent trains, made up of small particles of light, which remained refulgent for a while, so that the track, winding swiftly in and out, backwards and forwards, could be distinctly made out till the light became exhausted. After a period of rest the process was repeated. Several deep-water species of Gorgonia and Antipathes (especially Riisea) showed a bright bluish phosphorescence when coming up in the trawl. An ophiuran also, like one of the Mediterranean species mentioned by Panceri, was exceedingly phosphorescent, emitting at the joints along the whole length of its arms a bright bluish-green light. Among the deep-sea fishes certain parts, either lateral organs or specialized parts of the head, are highly phosphorescent.

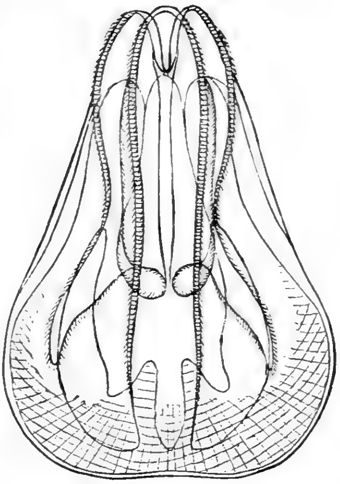


Fig. 128. — Mnemiopsis Leidyi. Somewhat reduced.

It is interesting to note that Professor Forel, who has studied the habits of the pelagic fauna of the large Swiss lakes, finds that, like the marine pelagic fauna, the animals marked for their transparency, especially the crustacea, sink to small depths during the day and come up at night, to feed upon the pelagic algæ.

I made no attempts to use the tow-net to ascertain the presence of foraminifera, radiolaria, or other pelagic animals, at a distance from the surface. All naturalists familiar with the use of the dip-net, the tow-net, or with their modifications first employed below the surface by Baur, know that the pelagic animals are driven from the immediate surface by winds and rain, or by some other cause, into moderate depths, where they may always be procured, while at greater depths they fail to be found. Such, at least, has been the experience of Johannes Müller, Claparède, and others, who have followed their method of fishing either at the surface or a little below it.

The evidence of specimens brought up by the "Challenger" nets from intermediate depths is inconclusive, since the ordinary tow-nets were used. These were lowered open, kept open while towing, and remained open while coming up. It is perfectly true, that, by differentiation of the contents of the several nets at one locality, some approximate results might be obtained, if the work were carried on for a long period; but an occasional haul taken by itself means nothing. The important desideratum is to devise a tow-net which will go down closed to any depth required, will then open and tow while the ship is in motion, and close again within a reasonable distance as it comes up. The collecting cylinder devised by Lieutenant-Commander Sigsbee meets some of these requirements.[1] He accompanied us on the "Blake," to superintend in person its first trial. It was sent down in thirty fathoms of water, from five to twenty-five fathoms, with quite a fresh breeze blowing, at about eleven in the morning, in full sunlight, — a time when, with a smooth sea, the pelagic animals would all have been on the surface. The cylinder worked most satisfactorily, and brought up a few Calani, hydroid medusæ, such as usually occur at the surface. A few slight changes were suggested by the designer, and Commander Bartlett recommended the addition of a wire-gauze trap, to facilitate the washing out of microscopic animals.

On the 1st of July the Sigsbee cylinder was tried for the second time, in Lat. 39° 59′ 16″ N., Lon. 70° 18′ 30″ W., in two hundred and sixty fathoms of water. The surface was

[1] Described in the chapter on the Equipment of the "Blake."

carefully explored with the tow-net, to see what pelagic animals might be found there; they were Calanus, Sagitta, annelid larvæ, hydroid medusæ, Squillæ embryos, Salpæ, and a few radiolarians. The cylinder, filled with water which had been strained through fine muslin, was then fastened to the dredging wire, and lowered, so as to collect the animals between five and fifty fathoms. The time taken by the cylinder in passing through that space was twenty-eight seconds. It was then drawn up, and the sieves and gauze trap washed with water, which had also previously been strained through fine muslin. The water was carefully examined; it contained the very same things which had a short time before been brought together with the tow-net and the scoop-net: nothing different was obtained by the cylinder. The radiolarians (two genera) were perhaps more numerous. A slight breeze having sprung up after the surface collections had been examined, the cylinder was operated a second time at this same station, adjusted for a depth of fifty to a hundred fathoms. Not only in this experiment, but in all the subsequent ones, the same precautions were taken in regard to straining the water which filled the cylinder at the start, as well as that used for washing out the sieve and the gauze trap. The messenger sent to detach and open the machine occupied twenty-one seconds in reaching the fifty-fathom point to which the cylinder was attached, and the cylinder thirty seconds in passing to the stop at one hundred fathoms. On examining the sieves, the more common surface forms, Calanus, Sagitta, annelid larvæ, hydroid medusæ, and Squillæ embryos, were wanting, and only two radiolarians of the same species as those from the upper levels were found. Nothing additional was brought up. The cylinder was lowered a third time to a depth of one hundred fathoms, the messenger occupied 45″ to open it, and the cylinder travelled from a hundred to a hundred and fifty fathoms (time 45″), so as to gather the animal life to be obtained between these limits. On drawing up the cylinder and washing out the sieve of the trap, not only did we find that the water contained nothing different from what had been brought together by the cylinder from the lesser depth, but it did not include even a single radiolarian.

On the 15th of July, in Lat. 34° 28′ 25″ N., Lon. 75° 22′ 50″ W., we tried the Sigsbee cylinder for a third time, in a depth of 1,632 fathoms. With the same precautions before and after using it, the cylinder was operated first between five and fifty fathoms (time 30″). The water was somewhat ruffled, and but little was found on the surface beyond a few crustacean larvæ and heteropods. The cylinder contained hydroids, fragments of siphonophores, pelagic algæ, crustacean larvæ, and heteropod eggs; forms which differed from those gathered at the surface, but were identical with the species obtained on previous days under more favorable conditions of the sea. Next, the cylinder was arranged for a depth of between fifty and a hundred fathoms (time of messenger 21″ from surface to fifty fathoms, time of cylinder 40″ to stopper from fifty to a hundred fathoms). The water was found to contain only a couple of Squillæ larvæ, similar to those fished up at the surface. The third time the cylinder went down at this station, it was lowered to collect from a hundred to a hundred and fifty fathoms (time of messenger from surface to a hundred fathoms 45″, time of cylinder in passing from a hundred to a hundred and fifty fathoms 45″). The water when examined contained nothing. No radiolarians were found at this station, either at the surface or at any depth to which the cylinder was lowered (one hundred and fifty fathoms).

The above experiments appear to prove conclusively that the surface fauna of the sea is really limited to a comparatively narrow belt in depth, and that there is no intermediate belt, so to speak, of animal life, between those living on the bottom, or close to it, and the surface pelagic fauna. It seems natural to suppose that this surface fauna only sinks out of reach of the disturbances of the top, and does not extend downward to any depth. The dependence of all the pelagic forms upon food which is most abundant at the surface, or near it, would naturally keep them where they found it in quantity.

The experiments in using the tow-net at depths of five hundred to one thousand fathoms, as was done by Mr. Murray on the "Challenger," were not conclusive, as has been already pointed out on a former occasion, while the so-called deep-sea

siphonophores, taken from the sounding-line by Dr. Studer on the "Gazelle," may have come, as I have so often observed in the Caribbean, from any depth. I do not mean, of course, to deny that there are deep-sea medusæ. The habit common to so many of our acalephs (Tima, Æquorea, Ptychogena, etc.) of swimming near the bottom is well known; Dactylometra moves near the bottom, and Polyclonia remains during the day turned up with the disc downwards on the mud bottom. I only wish to call attention to the uncertain methods adopted for determining at what depth they actually live.

One must have sailed through miles of Salpæ, with the associated crustacean, annelid, and mollusk larvæ, the acalephs, especially the oceanic siphonophores, the pteropods and heteropods, with the radiolarians, globigerinæ, and algæ, to form an idea of how rich a field still remains to be explored. The pelagic fauna in the course of the Gulf Stream is probably not surpassed in variety by that of any other part of the ocean.

When they die and decompose, the pelagic forms, both animal and vegetable, sink to the bottom fast enough to form an important part of the food supply of the deep-sea animals, as can easily be ascertained by examining the intestines of the deep-water echinoderms. We can thus account for the presence at great depths of much of the necessary plant-food needed for the herbivorous types living in the continental and abyssal regions. The variety and abundance of the pelagic fauna and flora, and their importance as food for marine animals, are as yet hardly realized.

According to the recent investigations of Regnard and Certes, decay and decomposition do not progress rapidly in deep water, the great pressure and the absence of light and heat being unfavorable to such progress. This mass of slowly decomposing material, which accumulates on the bottom of the ocean, mixing with the ooze, forms the organic slime which all dredgers have brought up, and which in early days of deep-sea investigations was regarded as a special organism of the highest scientific interest.

There seemed something providential, indeed, in the existence of this primordial pap, laid out in the thinnest layers over the

whole floor of the oceanic basins, in which the lower forms only needed to roll round to find all the food they could absorb. The naturalists of the "Challenger," who introduced Bathybius to the scientific world, were the first also gracefully to recant before the overwhelming proof of its non-existence which they themselves had collected.[1] But it still figures in some quarters as a prominent organism, which the Haeckelian theory of the views of creation demand. The younger Sars and Alphonse Milne-Edwards have also found this sheet of organic matter, the nature of which is certainly not Bathybius in the sense in which it is understood by Haeckel.

A number of the marine animals ultimately depend for their food upon the pelagic fauna. The fishes feed upon the hosts of free-swimming crustacea, many of which develop with immense rapidity;[2] these in their turn depend for their food upon smaller creatures floating in the water, and found everywhere in the track of currents. There can be no better evidence of the mass of food contained in the sea than is afforded by the examination of the contents of a tow-net any night. Pour the contents into a glass jar, and note the edge of the vessel exposed to the light, — it is covered with crustacea, annelids, and mollusks; and examine also the residue at the bottom, — a true broth, consisting of the carcasses of all the minute shore and pelagic animals, and a mass of spores of all sorts of marine plants. This broth is used in the Newport Laboratory to feed young fishes and other embryos kept in confinement.

Nowhere do we see the struggle for existence going on so visibly as among the pelagic animals. They all prey one upon the other. The acalephs swallow hosts of minute crustacea, which in their turn are filled with embryos of crustacea smaller than themselves, or with spores of algæ.

The crustacea, large and small, form the main food supply of the young fishes which dart about in search of nourishment in

[1] The naturalists of the "Challenger" showed that *bathybius* was only flocculent precipitate of a sulphate of lime, thrown down from salt water by organic matter in the presence of alcohol.

[2] Of some copepods there are no less than thirty generations in three weeks; so that, with ample food and in the absence of enemies, the progeny soon passes beyond calculation.

the smooth streaks of the surface formed by the currents and winds. The mollusks in their turn, according to their size and activity, are either eaten or are the eaters of some animals more helpless than themselves. While the pelagic forms can move about from place to place in search of more abundant food, the more sedentary types must depend on the supply dropped in their immediate vicinity, or brought to them by currents.

It is difficult, in this gigantic struggle for food going on among the pelagic animals, to trace the effect of protective agencies. While undoubtedly we seem to be able to satisfy ourselves as to the efficiency of various causes, such as transparency, the extraordinary development of locomotory organs, or coloration, to take the pelagic types at certain stages out of reach of danger, yet there are in the course of the development of nearly all these pelagic types long periods during which the embryos are more than ever subject to destruction, at the very time when they would seem to have specially adapted themselves to surrounding circumstances. Probably at no time during the life of many crustaceans do they run so imminent a risk of destruction as during their zoea stage. (Figs. 129, 130, 131.) Left at the mercy of every current or ripple, they fall a prey to acalephs, to polyps, to cephalopods, and especially to young fishes, in spite of the huge appendages which seem at first sight to serve as protests against being swallowed by their smaller enemies. It would carry me too far to repeat in detail how many of our fishes devour minute organisms; how many mollusks and polyps live upon the most diminutive denizens of the seas, both animal and vegetable; how the echinoderms find their food by swallowing mud filled with living foraminifera or dead organic matter; and how the minute pelagic crustacea act as scavengers upon all dead animals.

The quantity of food contained even in apparently clear sea-water can readily be tested by leaving a shallow dish of it to settle during the night, and examining the bottom on the following day, when it will be found to be covered by a considerable amount of fine silt, made up of animal and vegetable fragments. (Fig. 132.)

It can readily be seen that, as far as the deep-sea forms are

concerned, they naturally procure their most abundant supply of food within a comparatively short distance from land, where all the detritus brought down by rivers, or formed by the action

Fig. 129. — Zoea of Carcinus. Greatly magnified.

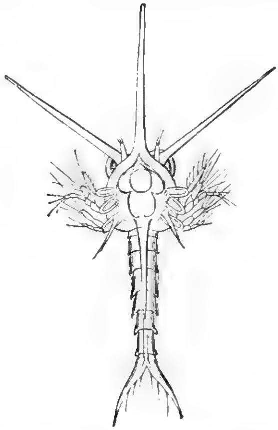


Fig. 130. — Panopus Embryo. Greatly magnified.

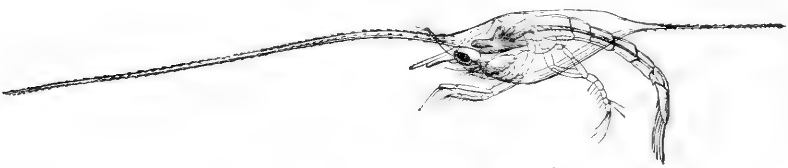


Fig. 131. — Zoea of Porcellana. $\frac{6}{1}$.

of the sea on the coast line, settles on the bottom around the slope of the continental areas. The larger materials are left close to the shores, and with increasing distance the detrital matter becomes smaller, till finally reduced to an impalpable material or solids in solution it finds its way to the most distant parts of the continental slopes, or is carried still farther by oceanic currents skirting the shores. As I have shown in the chapter on the Florida Reefs, the distribution of the deep-sea fauna is really a question of food; and we may expect to find it most abundant upon the continental shelf,—along the lines to which the greatest amount of detritus is carried by the incessant action of the varied winds, tides, and currents to which the sea-shore is exposed.

The wide bathymetrical range of species belonging to the principal groups of the animal kingdom shows that nearly all littoral types can adapt themselves to the conditions of the deep sea; and there seems to be no reason why, in the oldest geolog-

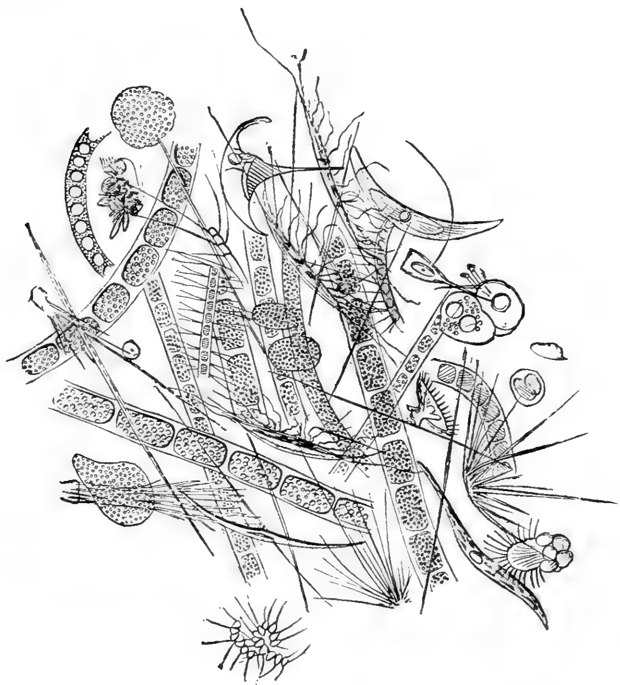


Fig. 132. — Pelagic Refuse. Magnified.

ical periods, the same adaptation should not have taken place. Yet, as we well know, no forms characteristic of the palæozoic period have been dredged from the abyssal regions of the sea. We are therefore warranted in assuming that such a migration did not take place from the littoral regions to the deep sea in palæozoic times, and that it was not before the end of the jurassic or commencement of the cretaceous that the littoral fauna began to find its way into deep water along the lines of the continental slopes. This colonization may have taken place, either through the gradual migration of the adults from their shallower habitat towards deeper regions, or, as I suggested in the report upon the sea-urchins collected by Pourtalès during the

first deep-sea expedition of the "Bibb," through the transportation of their pelagic larvæ by currents to more and more distant regions; much as we account for the extension of certain deep-sea faunæ, into adjoining geographical districts, as in the case of the northern extension of many Florida species far towards the coast of New England.

. It seems difficult for us to speculate on the origin of the pelagic fauna. Going back to the earliest fossiliferous periods, when the marine fauna was made up of pteropods, gasteropods, sponges, crinoids, graptolites, brachiopods, and crustaceans, we have animal types whose development in these early days must have been similar to that of their recent allies. Their youngest stages must already at that time, as are their representatives in our day, have associated with true pelagic types as part of the littoral pelagic fauna of the period. There is no reason why the true pelagic types of those times should not hold to the free-swimming embryo of the earlier marine faunæ the same relations which they hold to those of our own. It seems, therefore, most natural to look upon the pelagic fauna of to-day and that of former geological periods as made up of embryonic types removed from the influences necessary for their full development, and which have remained thus permanently in embryonic stages, even after a time reproducing themselves, as other larval forms are now capable of doing. But to consider that the littoral forms were developed from pelagic types, as has been suggested by Moseley, does not seem to be warranted by the embryological history of marine invertebrates.

Associated with the pelagic animals we find in all latitudes minute algæ, covering immense stretches of sea, often in sufficient quantities to discolor the water. The black and white water of the arctic, the so-called feeding-ground of whales, is mainly made up of diatoms, with which are also found pelagic animals. The color of the Red Sea is due to a minute alga, forming huge patches of a blood-red tint. A similar phenomenon is described by Darwin on the coasts of Chili and of Peru, where I have frequently seen it myself. In the Gulf of Mexico a pelagic alga, identical, probably, with that of the Red Sea (*Trichodesmium erythræum*) (Fig. 133), is seen on calm days, in

long trains or patches of a dirty yellow color. Dr. Farlow has identified as the same alga the pelagic plant found on one occasion north of Cape Hatteras, tinting the surface of the sea a dirty yellow for an area of about a quarter of a mile in length

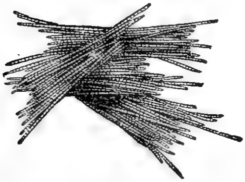


Fig. 133. — Trichodesmium erythræum. $\frac{8}{1}$.

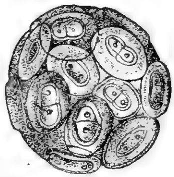


Fig. 134. — Coccosphere. $\frac{600}{1}$. (Chall.)

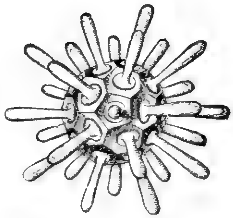


Fig. 135. — Rhabdosphere. $\frac{150}{1}$. (Chall.)

by a hundred yards in width. This pelagic alga has been aptly described as resembling minute sheaves and bundles of chopped hay. Coccospheres (Fig. 134) and rhabdospheres (Fig. 135) are calcareous pelagic surface organisms, of which the tests and fragments, coccoliths and rhabdoliths, occur in numbers in globigerina ooze. They have been studied by the naturalists of the "Challenger," and Thomson regards them as calcareous algæ of a peculiar form. They are found in abundance in the stomachs of Salpæ.

In addition to these smaller algæ, which are indeed the true inhabitants of the surface, and flourish equally well in all parts of the ocean,—in the central parts of the Gulf of Mexico, along the Atlantic coast of the United States, or on the west coast of South America,—we find some of the higher algæ, but these are confined to very much more limited areas. Sir Joseph Hooker has described the giant kelp in the floating condition in which it ranges over a wide extent of the Southern Ocean. A similar species of kelp occurs in the Gulf of Georgia, where it serves as a refuge to a host of marine animals, which are sheltered within the comparatively quiet area occupied by it. Both in the Atlantic and Pacific, large tracts are covered by a species of Sargassum (Fig. 136), which in the Atlantic has given its name to the area known as the Sargasso Sea.[1]

[1] The Sargasso Sea is an immense body of warm water of 1,000 miles in diameter, with a thickness of 300 fathoms, the surface temperature of 22° C., diminishing

This weed is not only pelagic, but is also found growing attached to rocks in the West Indies and along the Florida

Fig. 136. — Gulf-Weed. $\frac{1}{2}$.

Reef,[1] but no locality is known which could furnish the supply of gulf-weed necessary to form the floating masses in the Atlantic. How it has assumed its pelagic life is not known, but it undoubtedly forms extensive narrow strips, long irregular trains

very slowly to 16° C. at that depth. It occupies in the central part of the southern North Atlantic the position of the area of greatest density of sea-water, — over 1.027.

[1] A Pacific species of Sargassum, which is occasionally found floating near the Sandwich Islands, grows quite abundantly on the coral reefs of Oahu and Maui.

of yellowish green or golden olive, reaching over the dark blue water of the Atlantic.

The "Challenger" sailed round this so-called Sargasso Sea, but nowhere encountered it in sufficient quantities to become an impediment to navigation. We meet with this gulf-weed everywhere in the Gulf of Mexico, but scattered and only in small patches, and to the leeward of the Windward Islands. It is very abundant in the old Bahama Channel, and moderately common all along the course of the Gulf Stream from off Charleston to Cape Hatteras. The largest mass of gulf-weed I have encountered was in making the passage from St. Thomas to Havana.[1] While steaming within sight of the northern shores of Porto Rico and of San Domingo, we were never out of sight of immense accumulations of gulf-weed, parts of which rose a few inches above the water, the whole forming long trains which trailed with the winds and currents. The weed became less and less common as we approached the old Bahama Channel. But these masses of Sargassum were of slight thickness, and were mere floating patches, more or less entangled.

The numerous young and tender leaves found on every stem show that the weed is in a most flourishing condition, and is not merely dead weed floating about in the great vortex of oceanic circulation. It is not known what becomes of the gulf-weed annually driven by the equatorial current through the passages of the West India Islands into the Caribbean. The bulk of the weed which passes through the Windward Passage probably finds its way through the Yucatan Channel and the Straits of Florida into the Gulf Stream proper, but its final fate is not known. The amount of gulf-weed met with north of Cape Hatteras in the track of the Gulf Stream is small; it gradually increases as one goes south.

One of the objects of the "Talisman" expedition was to investigate the Sargasso Sea. The French explorers "nowhere met the enormous masses of floating Sargassum, which the old navigators compared to floating prairies." While sailing, the

[1] Commander Bartlett found large masses of gulf-weed on the southern edge of the Gulf Stream.

"Talisman" constantly crossed long bands of Sargassum trailing according to the direction of the winds and the currents, and forming larger or smaller patches, which were, however, rarely more than four or five yards square. Yet the "Talisman" crossed the Sargasso Sea from north to south in the areas indicated in the charts as the most prolific in Sargassum.

The weed as described by the younger Milne-Edwards does not differ from that which we have frequently examined. The central stalk and the basal leaves are usually of a brownish tint, the terminal leaves, on the contrary, of a greenish-yellow golden tint. The same animals as those commonly found in the gulf-weed of the West Indies were collected by the "Talisman." The number of fishes alone, perhaps, is somewhat more varied. The botanist attached to the expedition did not succeed in finding any branches with reproductive organs, although the terminal shoots were in most active states of development; and he came to the conclusion, as Harvey and others had done before him, that, while pelagic, the Sargassum increases merely like a cutting of extraordinary vitality. We were not fortunate enough to find it in fructification, but Professor Moseley states that he saw specimens covered with fructification in Harrington Sound, Bermudas.

Only by placing a piece of the gulf-weed in a jar of sea-water, with abundant space for it to expand, do we get an idea of its beauty and its graceful form. The delicate fronds, of all shades, from deep olive to golden yellow, are often crossed by a delicate tracery of hydroids and of bryozoan reticulation, which stands out in bold relief of white upon a dark background.

In the "Narrative of the Challenger" is given a list of the species of animals occurring on the Sargassum. Many observers have described the antics performed by the hosts of crustacea when shaken out of their hiding-places, and have dwelt at length on the phenomena of mimicry noticed among the crustacea, mollusks, annelids, and other animals which make their abode among the fronds, stems, or air-vessels of the gulf-weed. At first glance the bunch of weed seems deserted, but shake it in a glass dish, and hundreds of many-colored denizens are seen rushing about in all directions, eager to return to

the particular spot best adapted to conceal them; and in a few minutes only the practised eye of the naturalist can detect their presence. Of course they do not all succeed in their first attempt at finding the fittest sheltering-place, and an occasional striking contrast formed by a white checkered crab upon a dark background, or some other equally great opposition, will reveal the presence of a straggler. But these stragglers quickly correct their error.

The Sargasso Sea of the North Atlantic covers a rather indefinite area between 22° and 36° of north latitude, and, according to the statements of the older navigators, the amount of Sargassum to be met with varies from occasional patches to masses large enough to impede the progress of sailing-vessels. The Sargasso Sea was seen by Columbus, and alarmed his companions, who looked upon it as an insuperable obstacle to their expedition. The Sargassum probably changes its position constantly, according to the seasons, the currents, and the direction of the wind; but within the area bounded by the Gulf Stream on the west, the equatorial current on the south, and the return current from the Azores and Canaries, the Sargassum has always been found in larger or smaller quantities.

We are perhaps justified in considering the great banks of Sargassum in the Atlantic, Pacific, and Southern Oceans as survivors of a single bank, which probably swept round the globe in the great equatorial current of pre-tertiary times. The origin of this ancient bank may be due to the littoral species of Sargassum still living to-day in the track of its former path.

Some of the pelagic animals we have spoken of are specially interesting from a physiological point of view, owing to their association with vegetable organisms. As early as 1851 Max Schultze noticed the presence of chlorophyll in planarians, in some infusoria, in fresh-water sponges, and in a few worms and crustacea.

Peculiar yellow cells were observed by Johannes Müller in radiolarians, and were at first supposed by him to be connected with their reproduction, while Haeckel, who detected the presence of starch in these cells, considered them as digestive

glands, and Vogt regarded the yellow cells of Velella (Figs. 137, 137*a*) and Porpita as liver cells.

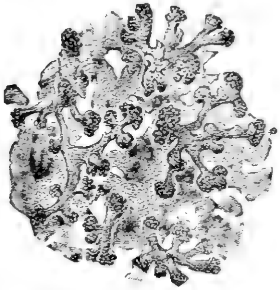


Fig. 137. — Velella mutica. Vascular canal filled with yellow cells, magnified.

In 1871 Cienkowsky expressed the opinion that these yellow cells were parasitic algæ, basing his view on the fact that they survive the radiolarians, multiply, and become encysted, — phenomena not in the least connected with the life process of radiolarians. In 1879 Hertwig discovered similar cells in actiniæ which he considered as unicellular algæ.

In 1881 Dr. Brandt confirmed Cienkowsky's discoveries, and strongly urged the parasitic nature of the cells. Geddes subsequently confirmed the views of Cienkowsky and Brandt, and traced the presence of starch and of a cell wall of true plant cellulose; he showed also that the chemical composition and the mode of division of these yellow cells were those of unicellular algæ, for which he proposed the name of Philozoön. The exposure of large quantities of radiolarians soon proved them to be studded with tiny gas globules, and a shoal of Velellæ yielded a large quantity of gas containing more than twenty-one per cent of oxygen. Dr. Geza Entz seems to have anticipated, as early as 1876, the observations and theoretical deductions of both Brandt and Geddes.

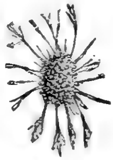


Fig. 137 *a*. — Single yellow cell, magnified.

In the relationship of these animals and plants, — for which the name of *Symbiosis*, given by De Bary to an association of dissimilar organisms, has been adopted, — it cannot be doubted that the animal cell must be benefited by the death of the vegetable cells which are digested, and that the animal cell is constantly producing carbonic acid and nitrogenous waste, which are of the first importance to the vegetable cell; the vegetable cell in its turn evolving oxygen under the action of sunlight, which is taken up by the surrounding animal tissues.

This association, as far as we know, must be very beneficial, for

the radiolarians and Velellæ (Fig. 138), in which the provision of philozoön is most abundant, survive longer in confinement than other pelagic animals. The common Polyclonia of Florida can be kept for weeks in jars, undoubtedly owing to the mass of philozoön found in its oral arms.

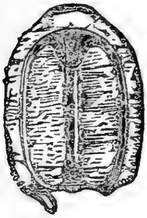


Fig. 138. — Velella Medusa with yellow cells, magnified.

Similar associations which do not have the same physiological value are found throughout the animal kingdom. It is difficult to draw the line between functional symbiosis and mere associations of position, in such cases as that of the Vorticellidæ, which fix themselves anywhere; that of the Bryozoa, growing on fronds of sea-weeds, or the tests of crabs or of mollusks; or that of many kinds of algæ and sponges, found growing on the carapace of crustacea. A similar association is that of the hermit crab and its house, of Phronima and its Doliolum quarters (Fig. 139), neither of which differs greatly from the somewhat less passive relationship of the oyster and its crab; of Fierasfer and the holothurians; of ophiurans and crustaceans living in the body of sponges; or of fishes swimming about in the midst of the tentacles of medusæ.

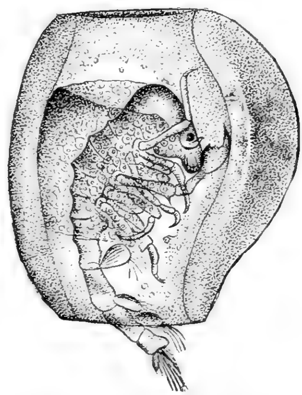


Fig. 139. — Phronima sedentaria. $\frac{2}{1}$.

More intimate still is the relationship existing between some species of crabs living in the branches of coral, or of worms or mollusks covered by gorgoniæ and crabs, where the presence of an associate modifies considerably the structure and mode of growth of the abode. From this we pass gradually to parasitism proper, where the organs of nutrition are specially developed, and those of locomotion degenerate. Again, free parasitism, we might almost call it, such as exists between insects and plants, is readily traced in a sort of commensalism of animals belonging to different classes of the animal kingdom, living together in a relationship almost close enough to be considered as functional; such as exists, for instance, between an-

nelids and starfishes, or crabs and actiniæ. Finally, we come to those communities among invertebrates where the subdivision of labor is carried out so far that the different individuals possess special functions. These cases belong to the same phenomena: they illustrate the interdependence of the animal and vegetable kingdoms, and the influence of special conditions of existence upon the development of the animal and vegetable life of our shores, continental slopes, and deep-sea basins.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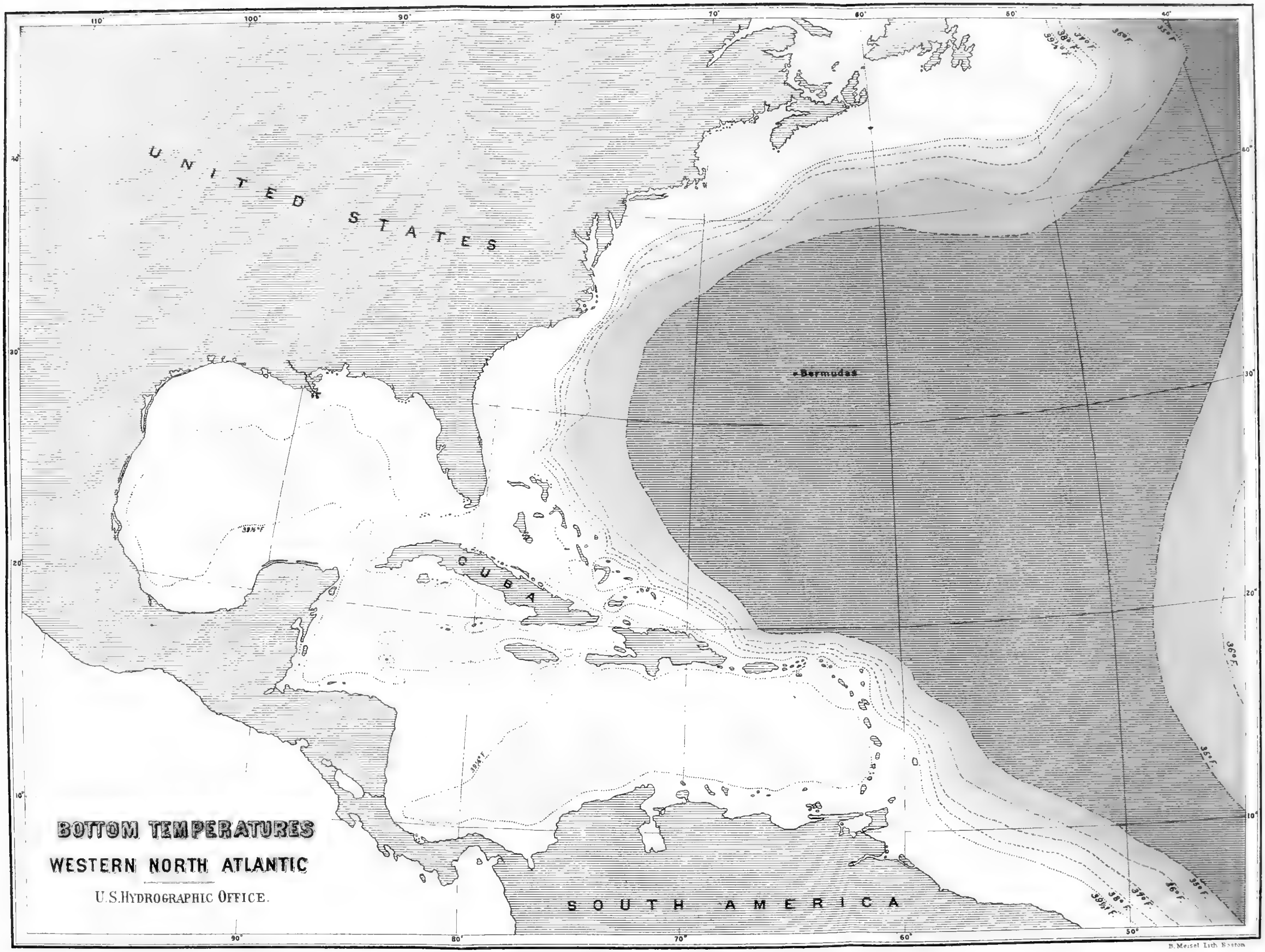
BOTTOM TEMPERATURES
WESTERN NORTH ATLANTIC
U.S. HYDROGRAPHIC OFFICE.

Fig. 140.



UNITED STATES
CUBA
Bermudas
SOUTH AMERICA
BOTTOM TEMPERATURES
WESTERN NORTH ATLANTIC
U.S. HYDROGRAPHIC OFFICE.
B. Meisel Lith Boston

X.

TEMPERATURES OF THE CARIBBEAN, GULF OF MEXICO, AND WESTERN ATLANTIC.

HAVING given the reader a general sketch of the configuration of the sea-bottom in the districts traversed by the "Blake," we may now pass to an examination of the temperatures and currents of the sheet of water covering that region. (Fig. 140.) The temperature sections of the Gulf of Mexico were obtained mainly by Lieutenant-Commander Sigsbee; those of the Caribbean and along the Gulf Stream, with the exception of the few observations made by the "Albatross," were taken by Commander J. R. Bartlett on the "Blake." They are here reproduced as they have been kindly sent to me by Professor J. E. Hilgard, Superintendent of the Coast Survey.[1]

Of course, during the cruises, soundings were taken with Sigsbee's modifica-

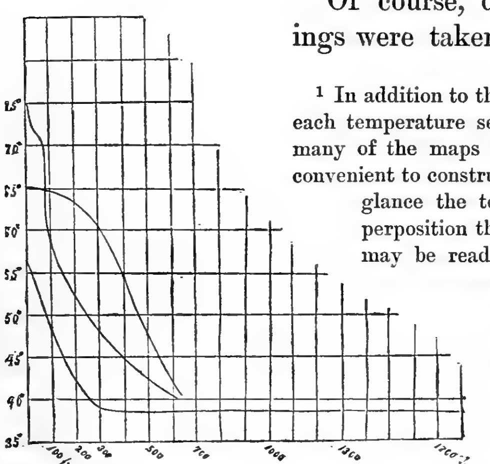


Fig. 141. — Temperature Sections. (Curves.)

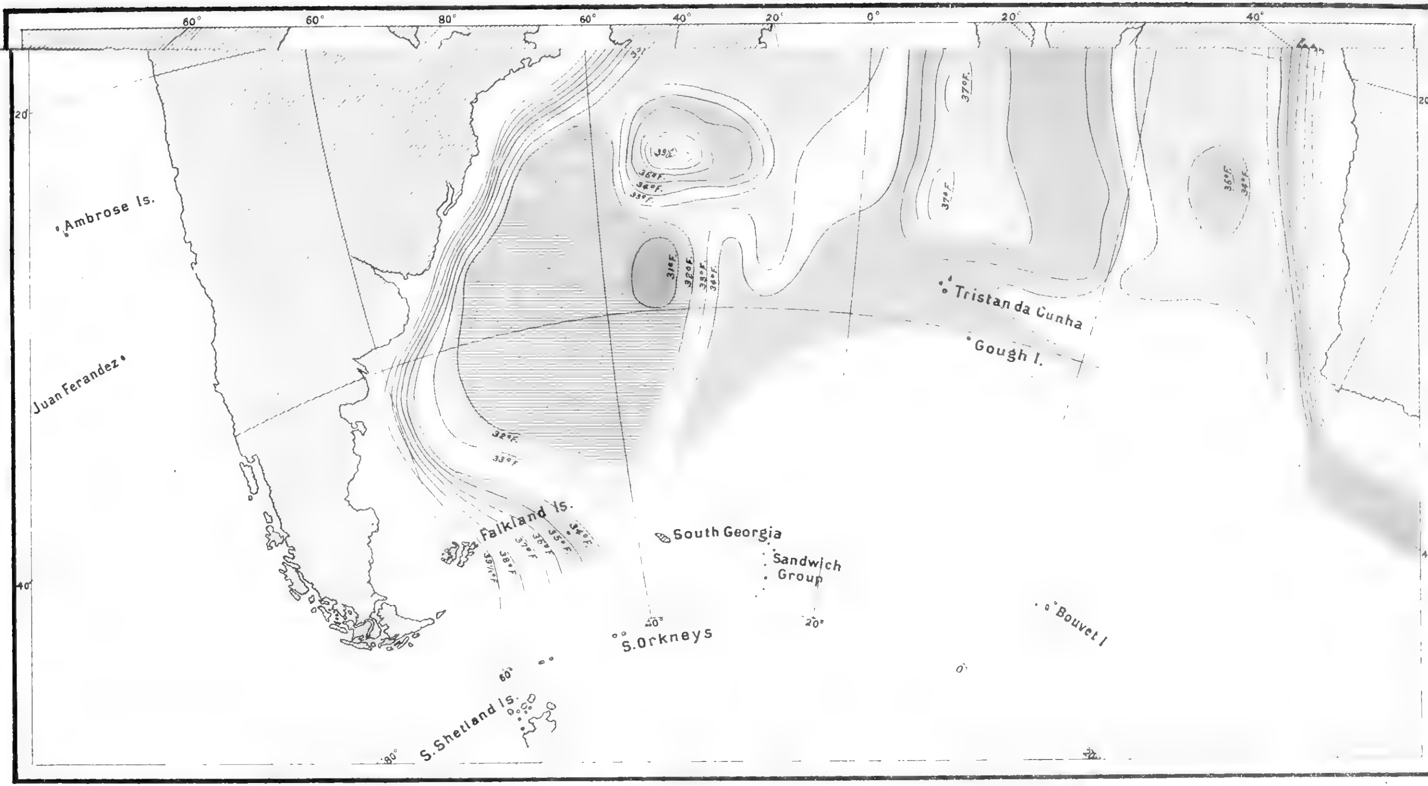
[1] In addition to the graphic method of representing each temperature section which has been adopted on many of the maps of this volume, it has been found convenient to construct curves (Fig. 141), showing at a glance the temperature at any depth. By superposition the curves of separate observations may be readily compared; in the same way, we may, by means of curves, bring to the eye at once the thermal conditions of such distant points as we wish to contrast. In attempting thus to set forth the temperature of currents, we should not forget that at every moment they are changing in direction and intensity, much as are the atmospheric currents; and their graphical representation merely gives us their most general features, leaving the local disturbances to be more or less accurately defined.

tion of Sir William Thomson's sounding-machine; the bottom and the surface temperatures, taken with the Miller-Casella thermometer, were compared from time to time with a standard. We obtained in the Caribbean and in the Gulf of Mexico a uniform bottom temperature of 39½° Fahrenheit, below six or seven hundred fathoms. The cause of this uniform bottom temperature is to be found in the depth of the passage between the Windward Islands, through which the cold waters of the Atlantic, from similar depths, force their way slowly northward, first into the Caribbean Sea, and then into the Gulf of Mexico, through the Straits of Yucatan. (Fig. 142.)

To Commander Bartlett I am indebted for information respecting the lines run between the islands. His report remains unpublished in the archives of the Coast Survey. The following extract from one of his letters will show the extent of the work done by the "Blake:" —

"I connected the islands by running traverses across the ridges. From St. Vincent to St. Lucia the ridge was only from 150 to 170 fathoms below the surface, with a channel of 400 fathoms near St. Vincent. The channel between St. Lucia and Martinique had 500 fathoms in mid-channel, sloping upward to each island. The channel between Martinique and Dominica was a tough one, and I thought I should never find a ridge. The soundings increased regularly on a ridge to 300 fathoms in mid-channel, where I got a sounding of 883 fathoms, and then 1,000 fathoms; beyond this the ridge was some ten miles to the westward, with an average depth of 400 fathoms, but I found two peaks with only 40 fathoms. The deep water from the Caribbean Sea makes in between Guadeloupe and Montserrat, but I found a ridge of about 300 fathoms connecting Antigua with Guadeloupe. In this channel I also found a peak with only 40 fathoms. I finished up the line connecting Saba Bank with St. Croix. I found the connection perfect, but the ridge has 700 fathoms water on it near St. Croix. There is 1,000 fathoms three miles north, and 1,800 fathoms five miles south of the ridge. I ran a line from Dog Island to White House Shoal, and back to Sombrero. Here I found a channel about ten miles wide, with 1,100 fathoms. The temperature was 38° at 1,100; outside, 37½° at 1,600, and 36½° at 2,500. I shall run a number of lines from St. Thomas to Sombrero, to be sure that this channel connects with the deep water off St. Thomas. I ran a line of soundings from the south end of Dominica to Avis Island. The soundings were regular at 1,000 fathoms to within ten miles of Avis Island."

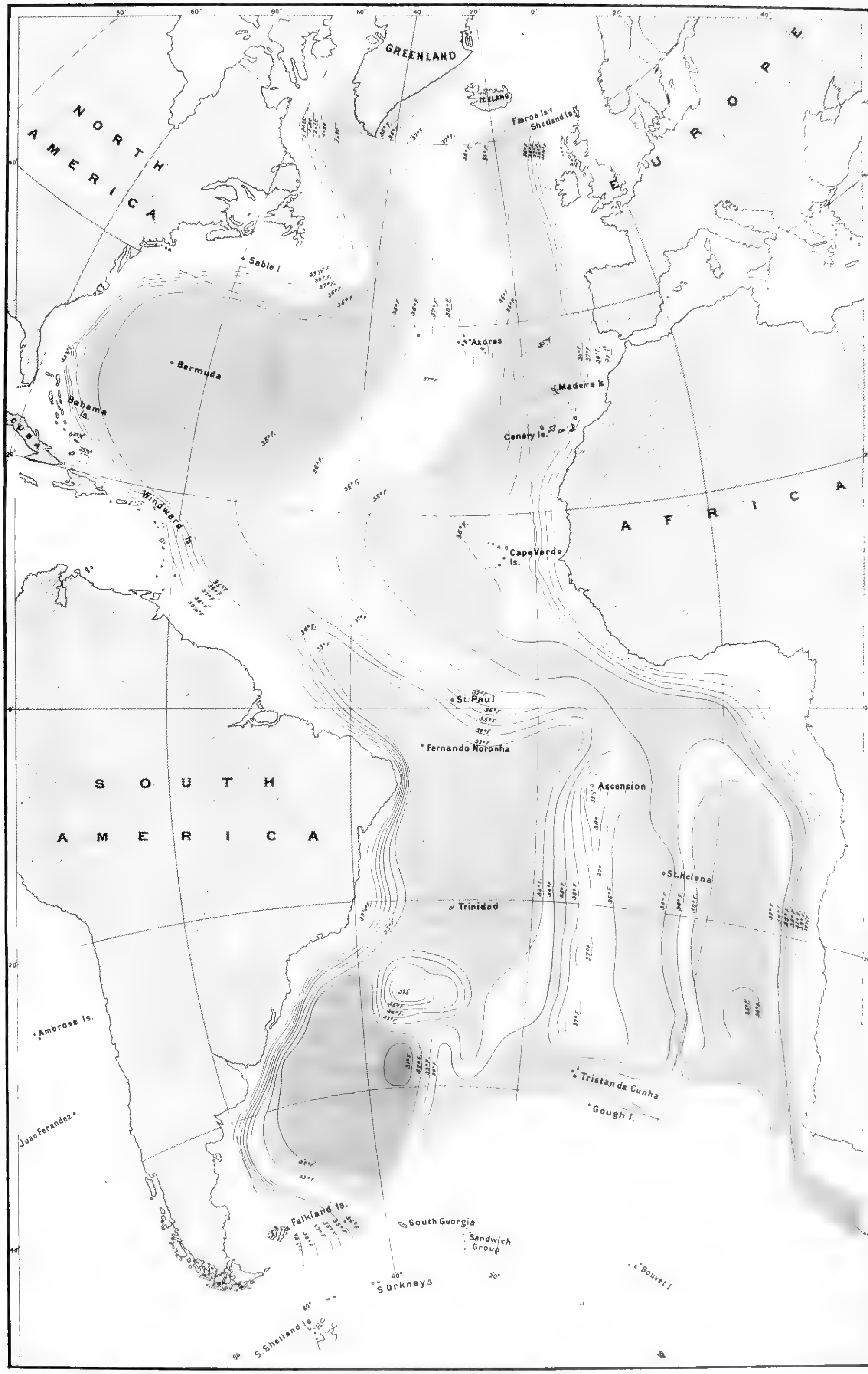
BOTTOM TEMPERATURES OF THE ATLANTIC. Fig. 142.



U. S. HYDROGRAPHIC OFFICE.

BOTTOM TEMPERATURES OF THE ATLANTIC.

Fig 142



U. S. HYDROGRAPHIC OFFICE.

The soundings made by Commander Bartlett after I left the "Blake," and by the "Albatross," to determine the ridges which unite the various islands between Sombrero and Trinidad, show plainly that the cold water of the bottom of the Caribbean can only come in through the passage between Sombrero and the Virgin Islands. This passage has a depth of about 1,100 fathoms, with a bottom temperature of 38°; the water which passes over the ridge connecting Santa Cruz with Porto Rico has a depth of about 900 fathoms and a temperature of 39½°. The five-hundred-fathom line, as I have stated, marks a large bank formed of all the islands to the south of Sombrero, including Dominica, with a narrow oceanic bay of 575 fathoms between it and Martinique; the five-hundred-fathom line again

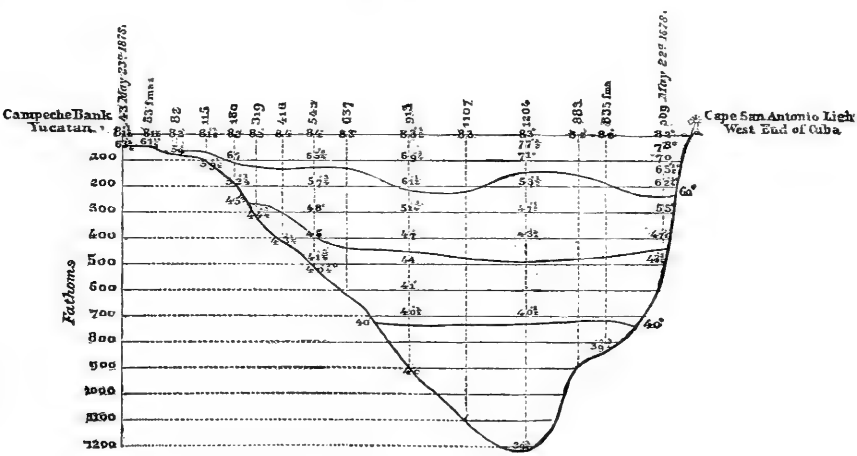


Fig. 143.

uniting all the islands to the south of it into one large spit, as a part of South America. Thus the bulk of the water forced into the Caribbean Sea has a comparatively high temperature, — an average, probably, of the temperature of the three-hundred-fathom line. The cold water of the Atlantic is, however, also forced into the western basin of the Caribbean through the Windward Passage, and this passes through the Yucatan Channel, between Cape San Antonio and the Yucatan Bank.

The greatest depth of the Yucatan Channel (Fig. 143) is somewhat more than 1,100 fathoms, so that the temperature of

the water which finds its way into the Gulf of Mexico is necessarily at its deepest point (2,119 fathoms) only that of the bottom of the Straits of Yucatan (1,127 fathoms), namely, 39½° F. This can only have the temperature of the deepest ridge separating the eastern Caribbean from the Atlantic (39½° F.). The depth of the channel through which the water of the Gulf ultimately finds its outlet is very much less (344 fathoms), and the Straits of Bemini, with a cross-section of not more than eleven square miles, are not half the width of the Straits of Yucatan. The temperature of the water at the bottom of the Gun Key Channel is much higher (see Fig. 158), with a far greater surface velocity than that of the current flowing into the Gulf of Mexico through the Straits of Yucatan.

It is therefore incredible that, with this huge mass of water pouring into the Gulf of Mexico, there should be anything like a cold current forcing its way up-hill into the Straits of Florida, as has been asserted on theoretical grounds. The channel at Gun Key can only discharge the surplus water by having a great velocity.

The soundings made by the "Challenger" off Sombrero on their line from Sombrero to Teneriffe, as well as the soundings north of St. Thomas on the line from St. Thomas to Bermudas (see Fig. 170), were fortunately both taken in March, at about the same time with those of Commander Bartlett.

On comparing the soundings taken by the "Blake" off Sombrero (Fig. 144), twenty miles from shore, with those of the "Challenger" (see Fig. 170), three hundred miles from shore, we find the surface temperature observed by the "Blake," and at a depth of fifty fathoms, slightly higher (2°), at 100 fathoms 2° less, at 200 fathoms 1° less. The temperature of 50° is reached at a depth of 350 fathoms by the "Challenger;" at 300 by the "Blake." The "Blake" observed 46° at 400 fathoms, the "Challenger" 45° at 425 fathoms, and at a depth of 700 fathoms both the "Challenger" and "Blake" record a temperature of 40°. The "Blake" serials show 40° to a depth of 900 fathoms, while the "Challenger" has at the same depth 39°. At the deepest point on that line (2,558 fathoms) the "Blake" observed a temperature of 36°, while at the same depth the

"Challenger" records 35.1°. These observations show, as we approach the coast, an increase of temperature to a depth of about 400 fathoms, and a diminution of temperature to a depth of about 1,700 fathoms.

In the section from Sombrero to Virgin Gorda (Fig. 144) across the Anegada Channel, the temperatures agree more closely with those of the Atlantic sections taken by the "Challenger" than with the more littoral one taken by the "Blake." There is a marked increase of temperature in the layers between 100 and 300 fathoms. Between 400 and 600 fathoms, however, the water is somewhat colder, and at the bottom the tem-

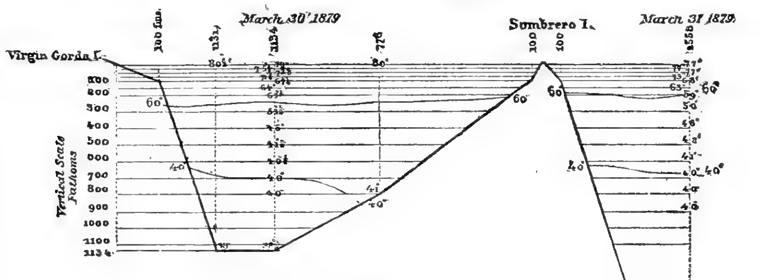


Fig. 144.

perature is nearly that of the corresponding depth three hundred miles at sea. The bottom temperature of this channel does not indicate that the cold water is thrown up along the gentler slope of the channel, as in the temperature sections across the Yucatan Channel (Fig. 143), and across the narrow part of the Straits of Florida. (Fig. 158.) The bottom temperature, 38° and 38½°, indicates that the basin and this channel are an oceanic tongue of the Atlantic, and that there must be a ridge, extending between Santa Cruz and Porto Rico, which separates it from the Caribbean basin.[1] Far inside of the Caribbean Sea,

[1] The temperature of 38½° also shows that the Anegada Channel is divided by a ridge from the deeper part of the oceanic basin of the western Atlantic to the north of the West Indies, as in that basin the temperature observed by the "Challenger" and by Lieutenant-Commander Brownson sinks to 36° in its deepest parts. Since this was written, the U. S. Fish Commission steamer "Albatross," Lieutenant-Commander Tanner, has developed a ridge running between Santa Cruz and Porto Rico, with a greatest depth of about 900 fathoms and a

within the ridges separating it from the Atlantic, the deepest soundings, such as those off Bequia, 1,591 fathoms, and off Martinique, 1,224 fathoms, indicate a bottom temperature of 39½°. From St. Thomas to Ham's Bluff (Santa Cruz), on the contrary, the temperature section seems to indicate that the deep water there (2,376 fathoms, with a bottom temperature of 38½°) is connected by a deep channel extending between Sombrero and Virgin Gorda with the cold Atlantic water. The temperatures in the section across the passage between Domi-

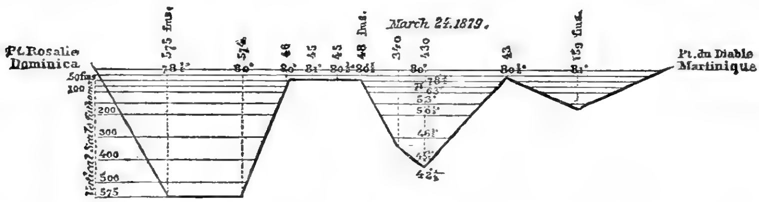


Fig. 145.

nica and Martinique (Fig. 145) show an extraordinary fall between 50 and 150 fathoms, — from 71° to 53°; then a much colder layer between 150 and 300 fathoms, with a bottom temperature of 42¼° at a depth of only 430 fathoms. The bottom

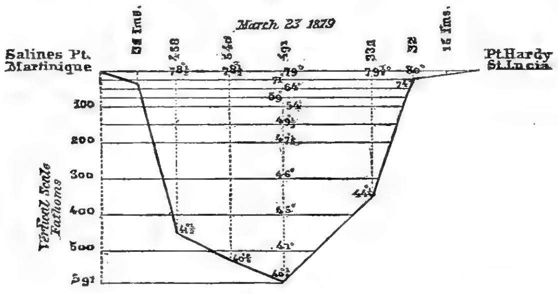


Fig. 146.

temperature in the northern part of the passage was 41° at a depth of 575 fathoms.

In a section from Martinique to St. Lucia (Fig. 146), with a somewhat larger area than that of the southern part of the pas-

bottom temperature of 39½°. The "Albatross" also ran a line across the eastern Caribbean, and found a bottom temperature of 39½° at the greatest depth recorded, — over 2,600 fathoms.

sage between Dominica and Martinique, the diminution of temperature between the surface and 100 fathoms ranges from 79° to 54°; a temperature of 46° is recorded at a depth of 300 fathoms, and a bottom temperature of 40¼° in 591 fathoms.

In the section of the passage between St. Lucia and St. Vincent (Fig. 147), we find 56° at a depth of 100 fathoms, 45¾° at 300 fathoms, 40° at 600 fathoms, and a bottom temperature of 39½° at 1,082 fathoms.

Across the Mona Passage there is but a small passage for cold

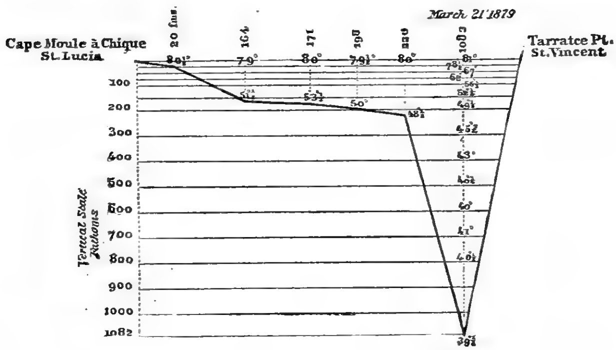


Fig. 147.

water between Direcho Island and Porto Rico. (Fig. 148.) We find there at a depth of 454 fathoms a bottom temperature of 44°, about what we have in the other passages. The larger area of this section across this passage, with an average depth

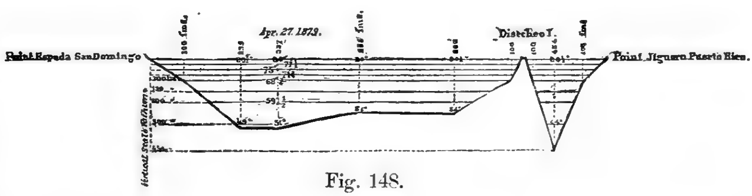


Fig. 148.

of 300 fathoms, shows a much higher temperature, the decrease being only 12° for the first 100 fathoms, and 9° for the second 100, with a bottom temperature of 51° at 337 fathoms. We notice in this section a temperature of 54° at 260 fathoms near Direcho Island, while it is 56° at a distance of about fifteen

miles in a depth of 56 fathoms. This cold water may come from the colder water of the deeper channel on the east of the island. The water is also colder near San Domingo, where we find at 339 fathoms 49°, while seven miles to the eastward, toward Porto Rico, it is 51° in 337 fathoms. This section is very similar to that of the Anegada Channel.

The temperature sections of the passages between the Windward Islands on the eastern side of the Caribbean — Dominica, Martinique, St. Lucia, and St. Vincent — are in striking contrast to those of the northern side, the Anegada, Mona, and Windward Passages. At a depth of 75 fathoms there is a difference of no less than 9°; at 200 fathoms, one of 10°; and one of 5° at 300 fathoms. The equilibrium is only restored at a depth of 600 fathoms, where we have again the temperature of 40°. We find repeated here on a smaller scale the variations of temperature at given depths near the equator and in the more temperate zones. A temperature of 41° has been observed in the Atlantic near the equator at a depth of only about 250 fathoms, while in the temperate latitudes both north and south of the equator we must go to a depth of at least 600 fathoms in one case, and of over 400 fathoms in the other, to obtain the same temperature. In other words, there must be an active lateral and upward flow of the cold water, and this establishes one of the primary causes of the equatorial oceanic circulation. It also shows that the temperature of the deepest point of the ridge which separates an inland sea, and thereby forms a mediterranean, is not necessarily that of the bottom of the enclosed sea. It is very evident that, supposing the ridge to have been only 300 fathoms deep, we could have a bottom temperature of 50°, which would indicate an oceanic ridge of 350 fathoms, on the same principles that have led Dr. Carpenter and others to speak of the bottom temperature of enclosed seas as assuming that minimum temperature.

The section across the Windward Passage (Fig. 149) bears a close resemblance to the oceanic temperature section of that region. The belt of water between 400 and 800 fathoms is, however, considerably warmer. It also resembles the section between Jamaica and San Domingo (Fig. 150), though the belt

of water between 200 and 500 fathoms is somewhat colder than in the Windward Passage. This is perhaps due to a similar cause to that which lowers the temperature of the water in the shallower sections of passages between the islands of the eastern edge of the Caribbean. As for instance in the Mona Passage,

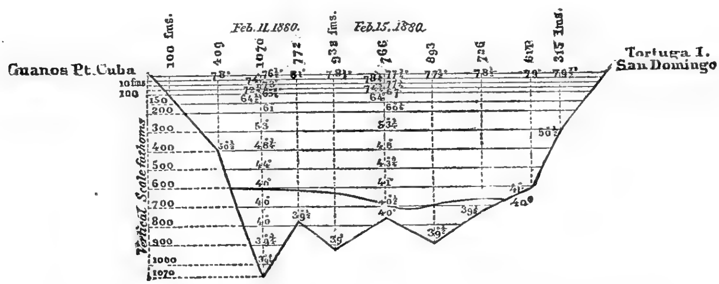


Fig. 149.

where a belt of water exists between 200 and 337 fathoms, colder than in the adjoining deeper passage between Cuba and San Domingo. Similarly the section between Jamaica and the Pedro Bank (Fig. 151) shows a slight diminution of temperature between 300 and 600 fathoms, which we are inclined to refer to

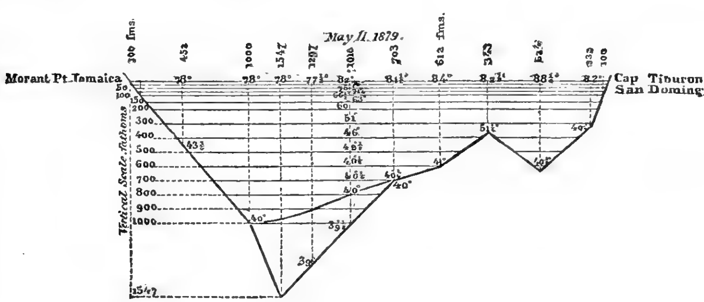


Fig. 150.

the existence of a ridge to the eastward, over which the colder water of the eastern Caribbean forces its way.

The section from Jamaica to San Domingo (Fig. 150) shows in the deep channel extending northeast of Jamaica, which connects the eastern basin of the Caribbean with the Honduras basin, a larger amount of cold water between 150 fathoms and

800 fathoms than we find in the corresponding belt of the section of the Windward Passage between Cuba and San Domingo. This section has in fact at that depth more the character of an oceanic section than has the section of the Windward Passage. This may be due, perhaps, to the fact that the water in the eastern part of the Caribbean is not so greatly superheated as in the belt to the northward of the Greater Antilles, from St. Thomas to San Domingo, which is forced into the funnel ending in the Old Bahama Channel, and finds an outlet into the Honduras basin of the Caribbean through the Windward

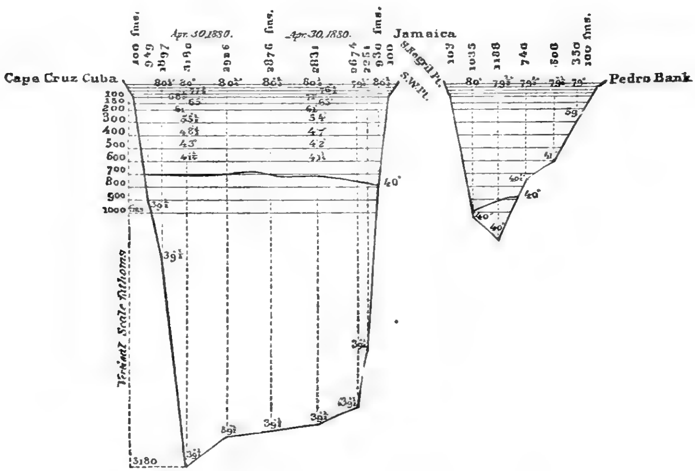


Fig. 151.

Passage. Or it may be that the colder water which flows into the eastern Caribbean through the Anegada Channel passes to the south of Porto Rico and San Domingo as far as the cañon which connects the eastern Caribbean with the Honduras basin.

In the section from Santiago de Cuba to Jamaica (Fig. 152) across the Formigas Bank, there are no marked departures from the temperatures of the section across the Windward Passage. This section goes across the eastern extremity of Bartlett's Deep (see also section, Fig. 153), and at a depth of 2,978 fathoms has a temperature of 39°. This temperature may be due to the cold water on the ridge of the Windward Passage (39° at 932

fathoms), or to that of 39° at a depth of 1,297 fathoms in the passage between Jamaica and San Domingo. Judging from the few bottom temperatures obtained between the Formigas Bank and Jamaica, the water of that section is slightly warmer, a temperature of 39° being obtained at a depth of 1,140 fathoms.

The bottom temperatures taken off Barbados, from 56 to 713 fathoms, on the southern and western sides of the island, show a remarkable diminution in temperature, as contrasted with the same depths of the serial line off Sombrero. There we have at

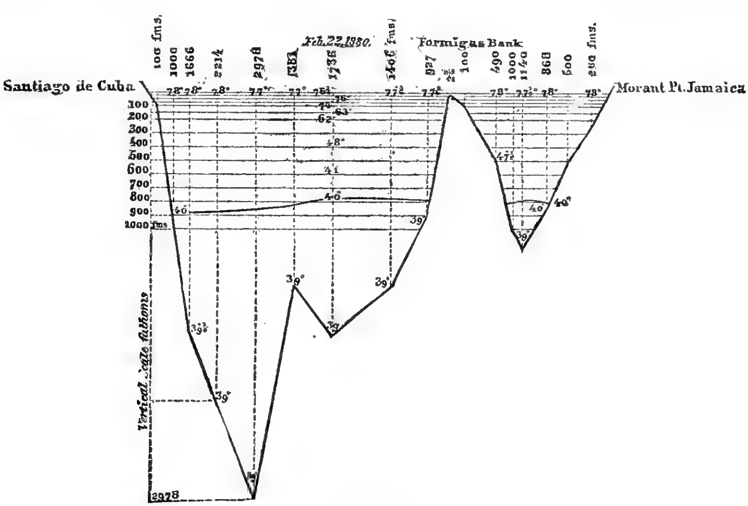


Fig. 152.

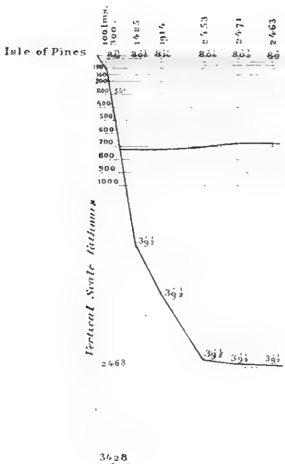
a depth of 50 fathoms a temperature higher by 2½° than off Barbados; at 100 fathoms it is 8½° higher, at 150 fathoms 7°, at 200 fathoms 8¾°, at 300 fathoms 4°, at 400 fathoms 1½°; and finally at 700 fathoms the temperatures become identical, 40°. The temperature lines off Sombrero were taken at the end of March, and those off Barbados at the beginning of March of the same year. These results agree with the temperatures taken to the southward by the "Challenger," between Pernambuco and Fernando Noronha. Near the last-named place the temperature falls to 60° at a depth of 50 fathoms; off Barbados the same temperature occurs at 82 fathoms. At 100 fathoms the temperature is 55°; it is the same at 150 fathoms off

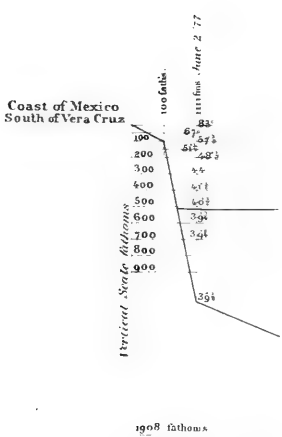
Barbados. The temperature is 45° at a depth of 225 fathoms, at 347 fathoms off Barbados; it is 40° at 350 fathoms, while the same temperature is found at a depth of 713 fathoms off Barbados. That is, the layer of water below 150 fathoms becomes gradually warmer as we go north from Pernambuco, the isothermal of 40° being at 350 fathoms off Pernambuco, while it is at 700 fathoms off Barbados and Sombrero. The isothermal of 50° is at 150 fathoms off Pernambuco, at 225 fathoms off Barbados, and at 350 fathoms off Sombrero.

A line of soundings southwest by south from Saline Point off Grenada shows the water to be as a whole colder than at similar depths off Barbados. Off Grenada at 400 fathoms we find 41°, at Barbados 44°; at 350 fathoms, the temperature is only about 1° colder off Grenada; at 300 fathoms, it is again 2° colder; at 150 fathoms, about 3°; and at 100 fathoms, only 1°. A series of bottom temperatures on the lee side of Grenada shows the water for depths between 100 and 400 fathoms to be considerably warmer than that of the corresponding depths standing in free communication with the Atlantic. At a depth of 92 fathoms, the water on the lee side is 3½° warmer than that of the same depth on the windward side. The same difference exists at 300 fathoms, and at 400 fathoms the temperature on the lee side is still 1° warmer.

The bottom temperatures on the lee side of St. Vincent show a similar difference. The bottom temperatures off St. Lucia on the lee side are slightly colder than those off St. Vincent and Grenada, but they are warmer than the temperatures at identical depths in the passage between St. Lucia and St. Vincent, and from St. Lucia to Martinique. The lower temperature is probably due to the deeper passages admitting cold water on each side of St. Lucia, as compared with the depths at which water pours into the Caribbean south of Grenada, or across the bank of the Grenadines and through the shallower passage between St. Vincent and Bequia. We must, however, call attention to the remarkably cold temperature occurring between 127 and 171 fathoms on the lee side of the Grenadines.

On the lee side of Martinique the bottom temperatures are still lower, — fully as low as those of the same depths in the


Isle of Pines
Vertical Scale fathoms
2468
3428


Coast of Mexico
South of Vera Cruz
100 faths.
June 2 '77
Vertical Scale fathoms
1908 fathoms

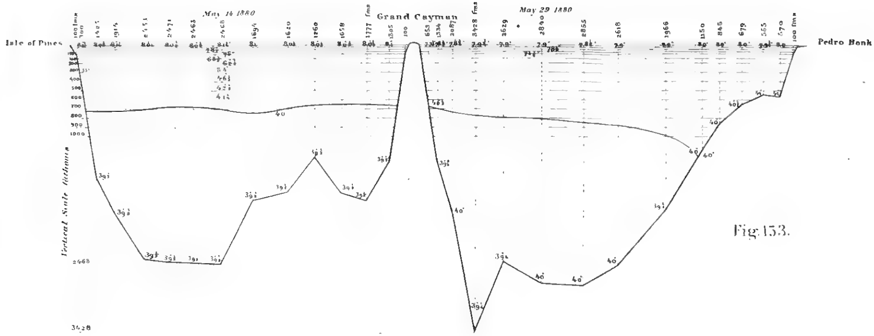


Fig. 153.

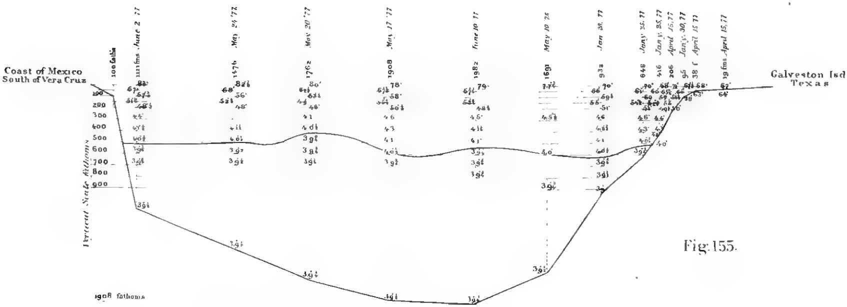


Fig. 155.

passage between Martinique and St. Lucia. They are actually lower than the temperatures of the corresponding depths observed in the passage between Martinique and Dominica.

On the Caribbean side of Dominica the series of bottom temperatures shows a marked increase from the surface to a depth of over 800 fathoms, and we must go to nearly 1,000 fathoms before we find the deep-sea isothermal of 39.7°. At 600 fathoms there is a temperature of over 40°; at 542 fathoms, of 42°. Comparing this with the temperatures outside of the Windward Islands, we find them considerably lower at a depth of 250 fathoms, and only slightly lower from that point to 600 fathoms.

Off Guadeloupe on the western side, the bottom temperatures between 62 fathoms and 300 fathoms are higher than at corresponding depths off Martinique, Dominica, and St. Lucia, and the same is the case off the islands of St. Kitts, Nevis, Montserrat, and the Saba Bank. This increase in temperature of the upper strata extends to a depth of over 250 fathoms. The broad bank which the above-named islands form upon the inner edge of the Caribbean seems to raise to an abnormal degree the temperature of the water which covers it, while the narrow bank of which the Grenadines form the crest appears to act more as a dividing ridge, cold water being brought nearer the surface on the Atlantic side of these islands, as is the case with the cold water on the dividing ridges in passages between adjoining islands.

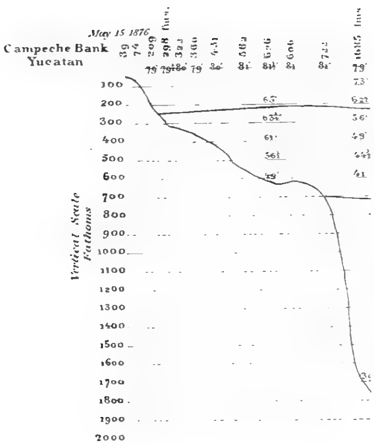
The same high temperature is continued in the line of bottom soundings observed off the western extremity of Santa Cruz, where at a depth of 625 fathoms we still find 41°; at 450 fathoms, 42½°; at 314 fathoms, 48°; and at 248 fathoms, 54½°. These temperatures agree well with those found outside, at similar depths, off Sombrero. That is, the strata of water to the eastward of the northern Windward Islands between 625 fathoms and 250 fathoms are much warmer than the same belt to the south, while the belt on the lee side between 250 and 100 fathoms is slightly colder. In the line of bottom temperatures between St. Thomas and Santa Cruz, we find at 218 fathoms only 51°, a temperature which corre-

sponds on the Atlantic side to a depth of but little less than 300 fathoms; but near the six-hundred-fathom line the temperatures of the inside section again agree with those of the oceanic section.

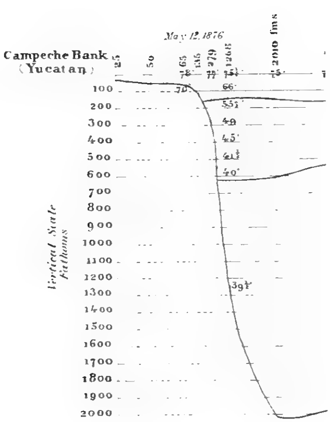
Across the Yucatan Channel the temperature section shows great similarity with the Atlantic section just outside of Sombrero. The water which finds its way into the Gulf of Mexico has nearly the same temperature as the water forced from the Atlantic over the eastern edge of the Caribbean basin through the passages between the Windward Islands. In the Gulf of Mexico itself, the sections from the Tortugas to Yucatan show a very decided increase of temperature below the one-hundred-fathom line. At 200 fathoms, the temperature is 65°; at 300 fathoms, it is 57°; at 400 fathoms, 50½°; at 500 fathoms, 41°; with a bottom temperature of 39° at 1,685 fathoms. That is, the temperature of the water between 150 and 600 fathoms is from 1½° to 4° warmer than the water which finds its way into the Gulf of Mexico. Compared with the temperature section of the Windward Passage (Cuba to San Domingo), the temperature of the Yucatan Channel line between 150 and 500 fathoms is from 1° to 2° warmer than that of a similar belt of water in the Windward Passage.

The temperature sections across the Gulf of Mexico show, on the whole, that the temperature of the upper strata between the surface and 150 fathoms diminishes much more rapidly than in the Caribbean, and that already at the one-hundred-fathom line it is lower than at the same depth in the Caribbean. From the one-hundred-fathom line the temperature falls very rapidly, the sectional lines across the Gulf showing a difference of 5° to 8° between 150 and 600 fathoms from the temperatures of corresponding depths in the Yucatan Channel. A comparison of temperatures in the Gulf of Mexico on the two sides of the Yucatan Bank brings out a striking contrast in temperature between the eastern and western sides of the Gulf.

The lines from the Tortugas to Yucatan (Fig. 154) have as a whole a warmer section than that of the Straits of Yucatan, while the lines from the Yucatan Bank to the coast of Mexico show at the same depth an increase of cold of more than 10° at



May 15 1876
Campeche Bank
Yucatan
1685 fms
Vertical Scale
Fathoms
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000



May 12, 1876
Campeche Bank
(Yucatan)
2010 fms
Vertical Scale
Fathoms
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

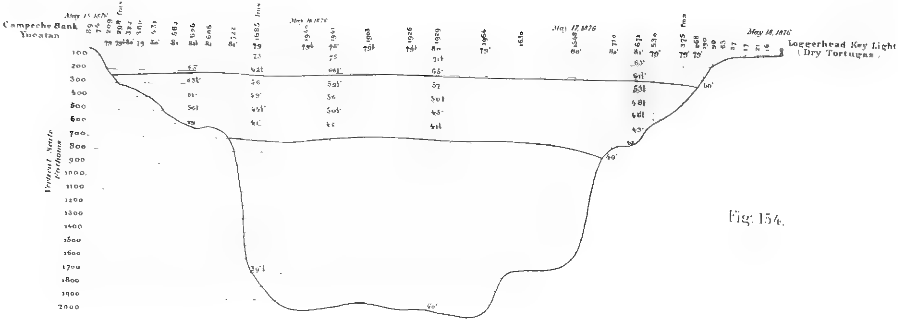


Fig: 154.

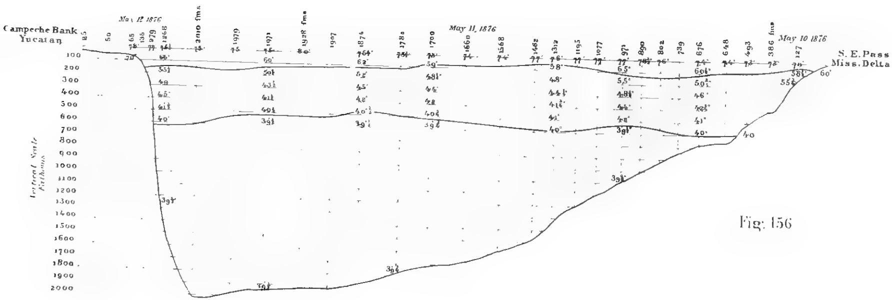


Fig: 156

100 fathoms, of 14° to 17° at 200 fathoms, of 9° to 13° at 300 fathoms, of 7° to 8° at 400 fathoms, and of 2° to 4° at the five-hundred-fathom line. The temperatures of the long lines from Mexico to Florida bring out the same differences, with the exception that there is a marked rise of the cold-water belt along the edge of the Florida Bank, which may be due to the general rising of the cold water, as in other sections along the planes of steep slopes. A comparison of the lines running north and south shows that the line from Vera Cruz to Galveston (Fig. 155) is colder than that from the Yucatan Bank to Louisiana. (Fig. 156.) The latter, in its turn, is colder than the line from

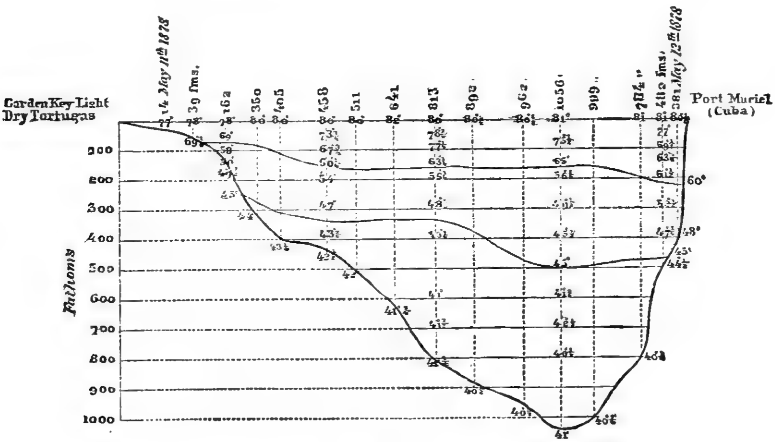


Fig. 157.

Yucatan to Santa Rosa, and that again colder than the line from the Yucatan Bank to the Tortugas. The presence of this thick layer of cold water between 150 fathoms and 600 fathoms — water colder than we find at the same depths in the adjoining Caribbean, or at the same depths in the Atlantic — can perhaps be explained by the increased evaporation of the superheated upper stratum cooling the water below it.

The sections from the Tortugas to Cuba (Fig. 157), and from Cape Florida across to Gun Key (Fig. 158), agree remarkably in their general character with the Yucatan section. The decrease of temperature is nearly the same. The layer of warm water is thicker close to the Cuban and Bahama side of the sec-

tions, showing that the temperature [1] of the outflow of the Gulf Stream across the Straits of Bemini is the same as that of the mass of water which lies to the westward of it. As it was conclusively proved by Professor Mitchell in 1867 that the current

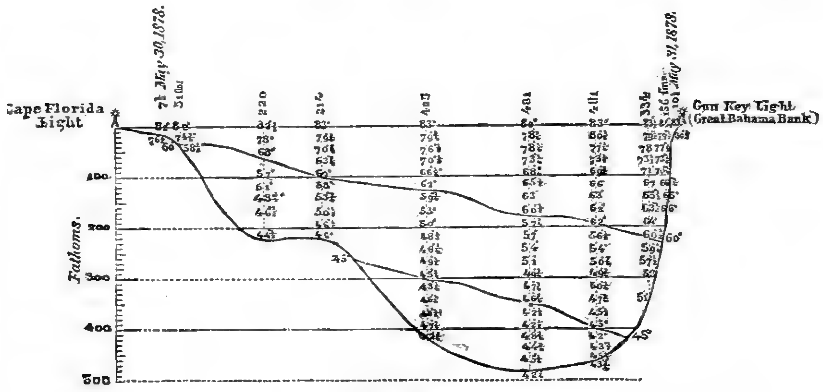


Fig. 158.

of the Gulf Stream extended to the bottom in the section between Havana and Key West, it is impossible any longer to account for the cold water of the sections across the Straits of Florida by an inflowing of cold water under the warmer water across the Straits of Bemini. As a further confirmation of this, we have the temperature of sections of the Gulf Stream taken off Jacksonville (Fig. 159), north and south of Cape Cañaveral

[1] I copy from Commander Bartlett's Report the cross-section taken by the "Blake" between Jupiter Inlet and Memory Rock: —

"At anchorage near Memory Rock, in four fathoms water. Surface, 78°; bottom, 78°.

5 miles.	Surface,	$81\frac{1}{2}$°	294	fathoms,	$56\frac{1}{2}$°
$4\frac{1}{2}$ "	"	$81\frac{1}{2}$°	347	"	52°
$4\frac{1}{2}$ "	"	$81\frac{1}{2}$°	395	"	45°
$4\frac{1}{2}$ "	"	$82\frac{1}{2}$°	439	"	44°
$5\frac{1}{2}$ "	"	83°	416	"	44°
5 "	"	83°	341	"	44°
$5\frac{3}{4}$ "	"	$82\frac{1}{2}$°	250	"	50°
5 "	"	80°	176	"	50°
$5\frac{1}{4}$ "	"	80°	95	"	57°
$2\frac{1}{4}$ "	"	80°	31	"	71°
$2\frac{3}{4}$ "	"	80°	10	"	78°

$2\frac{1}{4}$ miles from shore.

"The area of this cross-section is 429,536,240 square feet, and, assuming the velocity at three knots, the delivery per hour would be 51,028,905,312,000 gallons."

(Figs. 160, 161), and in 1853 off Cape Cañaveral (Fig. 162), off St. Simon's Island, Ga. (Fig. 163), and off Charleston, S. C., by Lieutenant-Commanders Craven and Maffitt. These sections

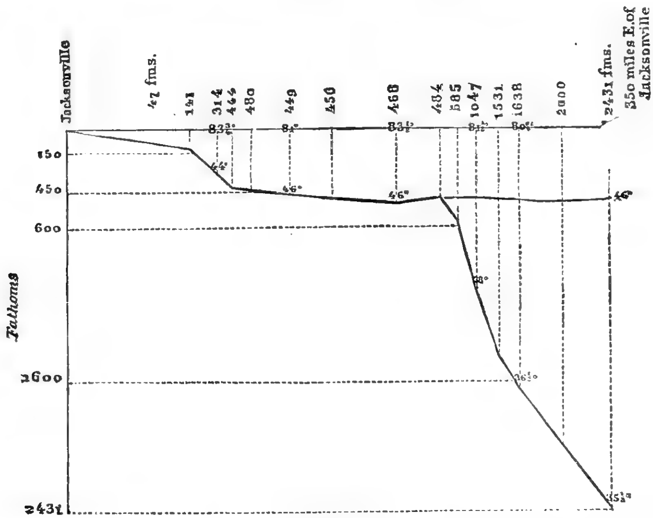


Fig. 159.

show that the temperatures of the line across the Gulf Stream from Gun Key are, as a whole, colder than those at the above-named points.

We seem here to have positive proof that the large body of

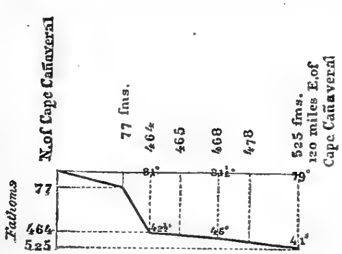


Fig. 160.

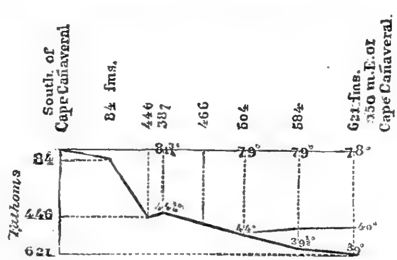


Fig. 161.

warm water to the north of the straits adjoining the colder water of the Gulf Stream must mainly derive its heat from the equatorial current itself, and that it does not come wholly from the superheated water of the Gulf of Mexico. Some of the

warmer water which joins the Florida Gulf Stream is driven into it through the Old Bahama Channel, the temperature of which seems to be very warm, being higher than we find it at equal depths to the eastward nearer the Windward Passage. The variable cold bands which have been traced in the course of the Gulf Stream may also be due not wholly to cold water

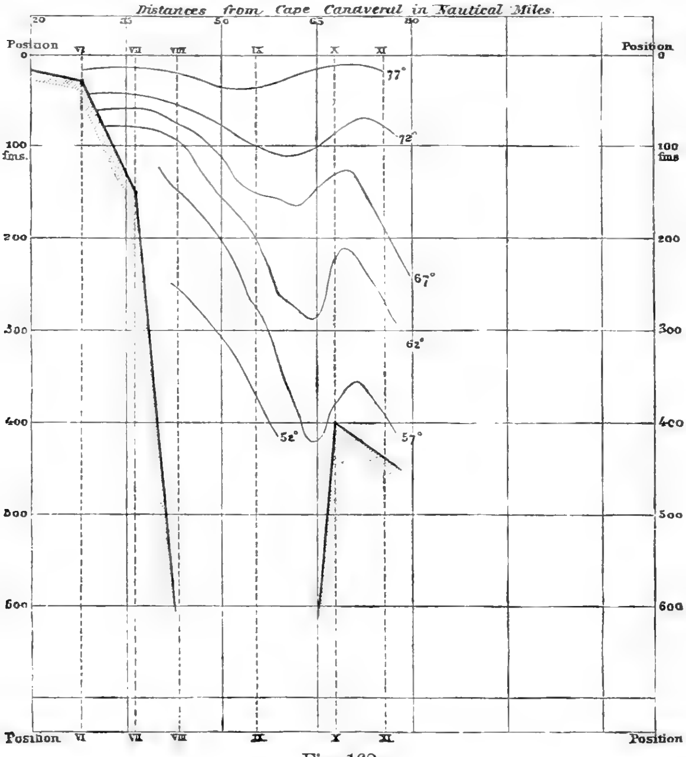


Fig. 162.

from an arctic current, but in part to the cold water of lower and colder layers of the Florida Stream itself.

A comparison of the temperatures of the different sections across the passages of the Windward Islands, the Straits of Florida, and the Straits of Bemini is interesting as showing that from the close agreement of the temperatures themselves across these lines there is nothing to indicate that a powerful current flows to the northward through the Straits of Bemini, or that similar currents, though of less velocity, pass through the Straits

of Yucatan and the Windward Passage. Nothing but actual observation has developed the fact that in the Straits of Bemini this current extends across the whole width of the straits and to the very bottom.[1] In the Windward Passage the dredgings

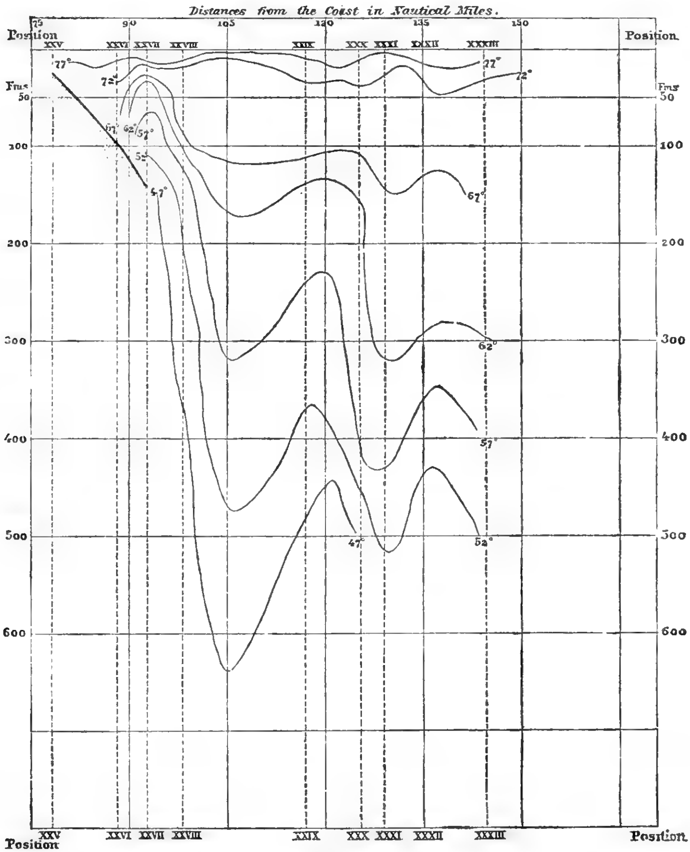


Fig. 163.—Off St. Simon's Island, Ga.

made on the dividing ridge and on each side of it indicate, from the presence of a large amount of pteropod silt on the southern

[1] Henry Mitchell looks upon the Nicholas and Santaren Channels, as well as the Providence and Exuma, not as channels proper worn by currents, but as portions of the ocean bed left undisturbed in the upheaval of the Bahamas. These channels are motionless masses of water, in which the decline of temperature with the depth is a little more rapid than in the track of the Gulf Stream. Mitchell also considers that the current of the Gulf Stream has had no share in cutting out the Straits of Florida.

face of the passage, and from the comparatively clean crest of the plateau across which the Atlantic waters are driven into the western Caribbean, that the current is flowing to the westward, and extends to the very bottom of the passage. Our experience in dredging between the Windward Islands was similar. We found the floor of the passages generally swept clear of all animal life, while it was only to the leeward of the dividing ridges

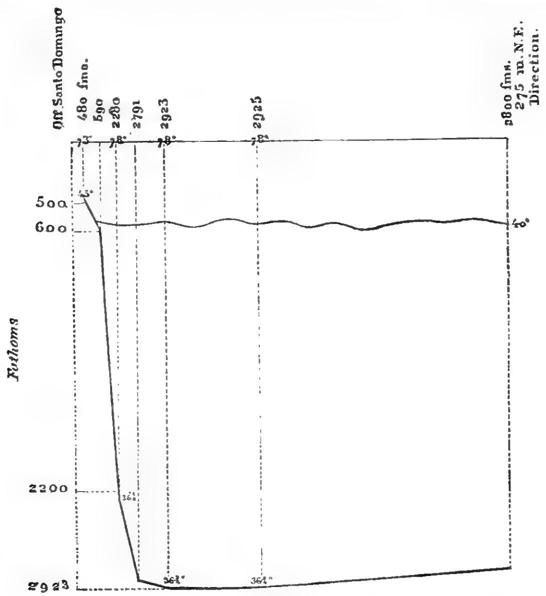


Fig. 164.

and of the islands, where the silt had a chance to accumulate, that marine animals were found in great profusion.

A similar experience followed us along the course of the Gulf Stream to the north of the Straits of Florida, while dredging across the Blake Plateau, off the coasts of Georgia and the Carolinas, and it was not until we reached the sea slope of the Gulf Stream trough near Cape Hatteras that we again came upon animal life in abundance; there we found it flourishing in the silt which had been rolled by the Gulf Stream along its bottom throughout its whole course from the Bahamas to Cape Hatteras.

It was only on the shore edge of the Gulf Stream, or in por-

tions where the current was of less velocity, that we found the greensand deposits, and made an occasional successful haul of the trawl or dredge. But the condition of the bottom speci-

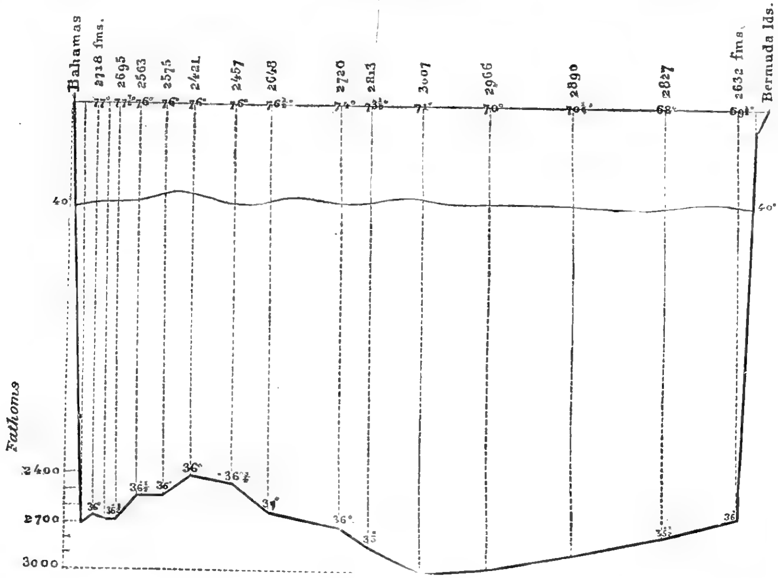


Fig. 165.

mens and the absence of silt from our hauls gave us every indication that the floor of the trough of the Gulf Stream was bare and hard, and practically swept clear of all *débris*, and consequently could afford little foothold for the development of animal life.

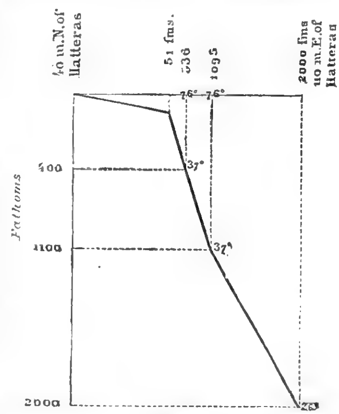


Fig. 166.

The soundings made by the "Blake" to the northward of San Domingo (Fig. 164) and to the eastward of the Bahamas, as far as the Bermudas (Fig. 165), and from the Bermudas again along the triangle bounded by the Bermudas, Cape Hatteras (Fig. 166), and the southern coast of Massachusetts (Fig. 167), have developed the following facts: namely, that there must be a ridge which prevents water colder than 36° from finding

its way north between the Bahamas and the Bermudas, and that there is a deep hole in which the enormous depth of 4,561 fathoms has been sounded by Lieutenant-Commander Brownson, with a temperature of 36°. The same temperature (between 36° and 37°) is found to be the bottom temperature in the sections taken to the northward, the only exceptions being a few colder soundings (a temperature of 35°) met within the lines off Norfolk, off Cape May, and off Nantucket, at a distance of about three hundred miles from the coast. At a depth of 600

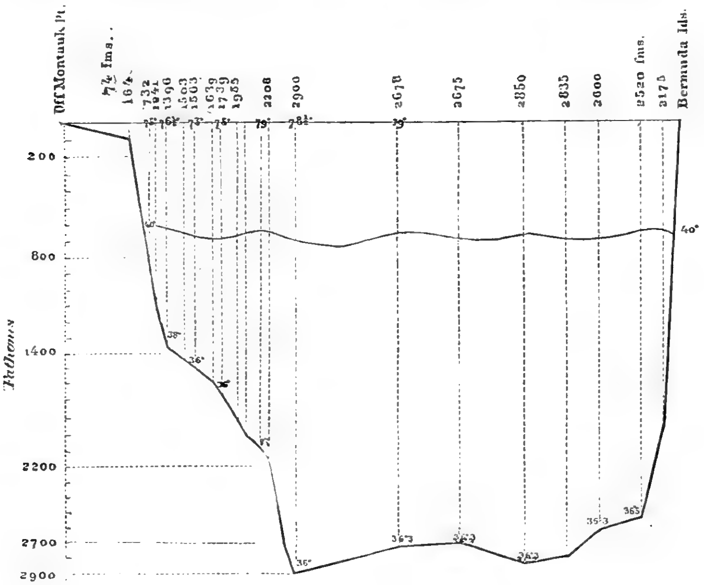


Fig. 167.

fathoms, off San Domingo, the temperature is 42°; at 500 fathoms, it is 45°. Off the northern extremity of the Bahamas it was about the same. Owing to the abruptness of the slope and the absence of serial soundings, we have no data regarding the thickness of this body of cold water, with a temperature of about 36°, which covers the bottom. Farther north this temperature begins at a depth of about 1,500 fathoms. In the sections taken off the Middle States, the temperature falls very rapidly, being 75° at the surface, while at a depth of 1,000 fathoms it is not more than 38°; and judging from the single section to the eastward

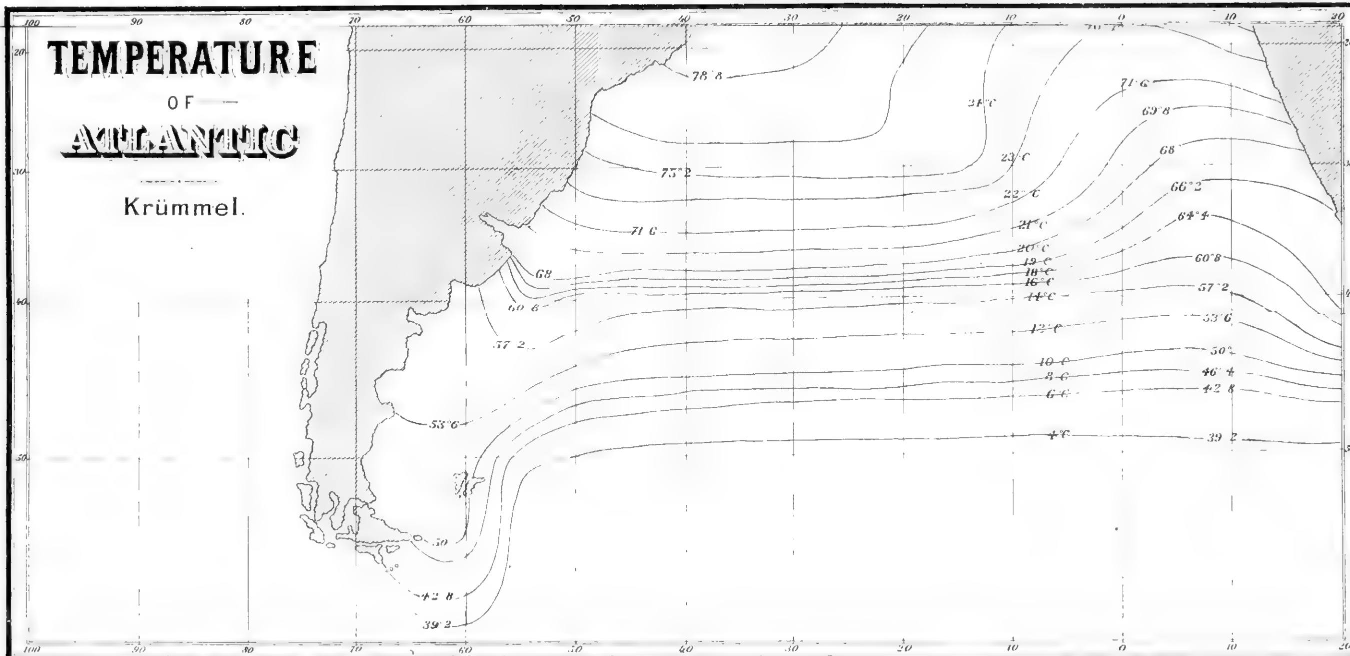
of the island of Eleuthera, the temperature appears to fall fully as fast. This would indicate that the whole mass of water between the Bermudas and the eastern shore of the Atlantic coast of the United States is moving northward under similar thermic conditions, disturbed only by the cold stream which forces itself southward from George's Bank, along the edge of the continental shelf, the exact limits of which are not yet ascertained.

The presence of a large body of cold water close to the east coast of New England [1] and the Middle States is shown by an examination of the sections which extend from the vicinity of Cape Hatteras to the northeastern end of George's Bank. The surface waters become gradually warmer as we pass to the eastward, rising, from temperatures of 55° at the surface and 42° at a depth of 71 fathoms, to a surface temperature of 68° and a bottom temperature of 38° at a depth of 980 fathoms. A similar but somewhat less increase in surface temperatures is traced in the lines run off Newport, of from 70° to 72°, and off Montauk, of from 74° to 76°, in passing from 129 to 1,394 fathoms, with bottom temperatures of 51° and 38°. Off Cape May the difference at the surface is still less, 77° to 78° while falling from a depth of 89 to 1,200 fathoms, with bottom temperatures of 56° and 39°. On the line immediately north of

[1] The recent explorations of the United States Fish Commission cover a belt about 160 miles long and from 10 to 25 miles wide, along the coast of southern New England, at a distance of 80 and 110 miles from the coast line, in depths between 65 and 700 fathoms. The soundings and dredgings show the southern continuation of the inshore cold belt, as well as the warm belt outside of it, and the cold deep-water belt. Professor Verrill says, speaking of the Gulf Stream slope: "The bottom along the upper part of this slope and the outermost portion of the adjacent plateau, in 65 to 150 fathoms, and sometimes to 200 fathoms or more, is bathed by the waters of the Gulf Stream. Consequently, the temperature of the bottom water along this belt is decidedly higher than it is along the shallower part of the plateau nearer the shore; in 30 to 60 fathoms. The Gulf Stream itself is usually limited in depth to about 150 fathoms, and often even less, in this region; below this, the temperature steadily decreases to the bottom of the ocean basin, becoming about 38°-37° in 1,000 to 1,500 fathoms, and falling to 37°-35° in 1,500 to 2,500 fathoms. We may, therefore, properly call the upper part of the slope, in about 65 to 150 fathoms, the warm belt. According to our observations, the bottom temperature of the warmer part of this belt, in 65 to 125 fathoms, is usually between 47° and 53° F. in summer and early autumn. Between 150 and 250 fathoms, the temperatures, though variable, are usually high enough to show more or less influence from the Gulf Stream."

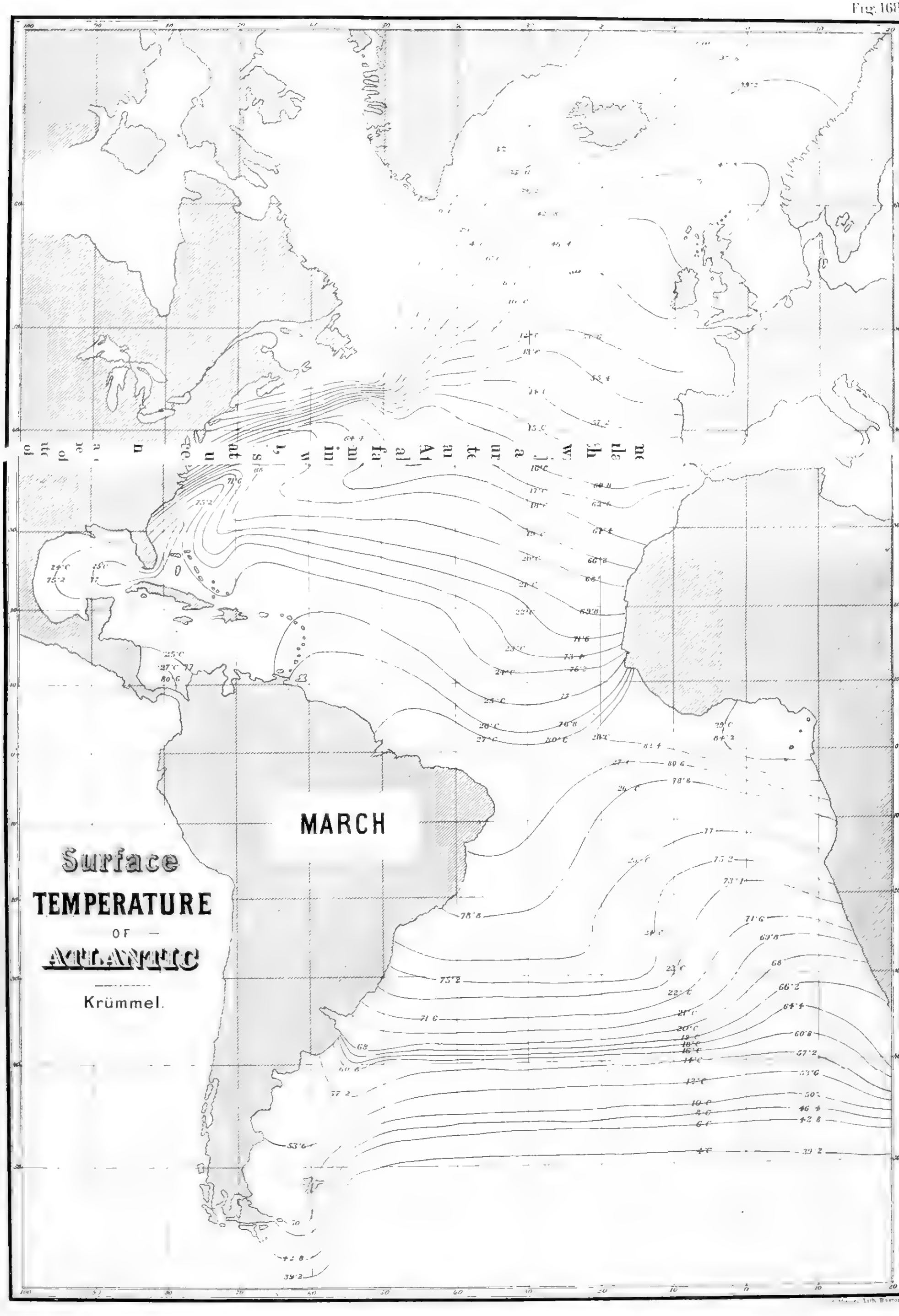
Hatteras, where the Gulf Stream and the northern current meet, we find temperatures of 79° and 60° at the surface, in depths of 65 and 1,000 fathoms, and a bottom temperature of 38° near the one-thousand-fathom line. South of Hatteras the surface temperature is more uniform, like that of the stream itself, with a far greater fall of temperature, 49½° at 178 fathoms, 39° at 464 fathoms, and 37° at 1,632 fathoms, until we reach the lines farther south, where, for the whole extent of the Gulf Stream, in its northern extension along the Blake Plateau, we have a bottom temperature of 44° at a depth of 400 fathoms, corresponding to the temperature, at the same depth, of the Gulf Stream when it passes through the Straits of Bemini.

Fig. 168.



TEMPERATURE
OF
ATLANTIC
Krümmel.
78°8
75°2
71°6
68
66°2
64°4
60°8
57°2
53°6
50
46°4
42°8
39°2
24°C
23°C
22°C
21°C
20°C
19°C
18°C
16°C
14°C
12°C
10°C
8°C
6°C
4°C
P. Meisel, Lith. Boston.

Fig. 168.



XI.

THE GULF STREAM.

THE Gulf Stream is the best known and at the same time the most remarkable example of the effect of oceanic circulation upon the distribution of temperature in connection with the currents of the North Atlantic. It has long been known to geographers that a cold current coming from Greenland joins the Labrador current, and extends in a southerly direction along the eastern coast of the United States, while a warm current pouring through the Straits of Florida flows in the opposite direction [1] along the coast of the southern Atlantic States, and is deflected from the Banks of Newfoundland, crossing the Atlantic diagonally. This body of warm water makes itself felt along the west coast of the British Islands, penetrating even as far as the coast of Spitzbergen, and perhaps beyond, to Nova Zembla. It is impossible to discuss the results of the more recent investigations of the Gulf Stream carried on by the "Blake," without including the general questions of oceanic circulation, and of the thermal conditions of the Atlantic in particular. I shall therefore briefly state such points, derived from the explorations of the "Challenger" and other expeditions, as will assist us in understanding the history and physics of this great oceanic current.

Sir Charles Lyell has called attention to the fact that in the

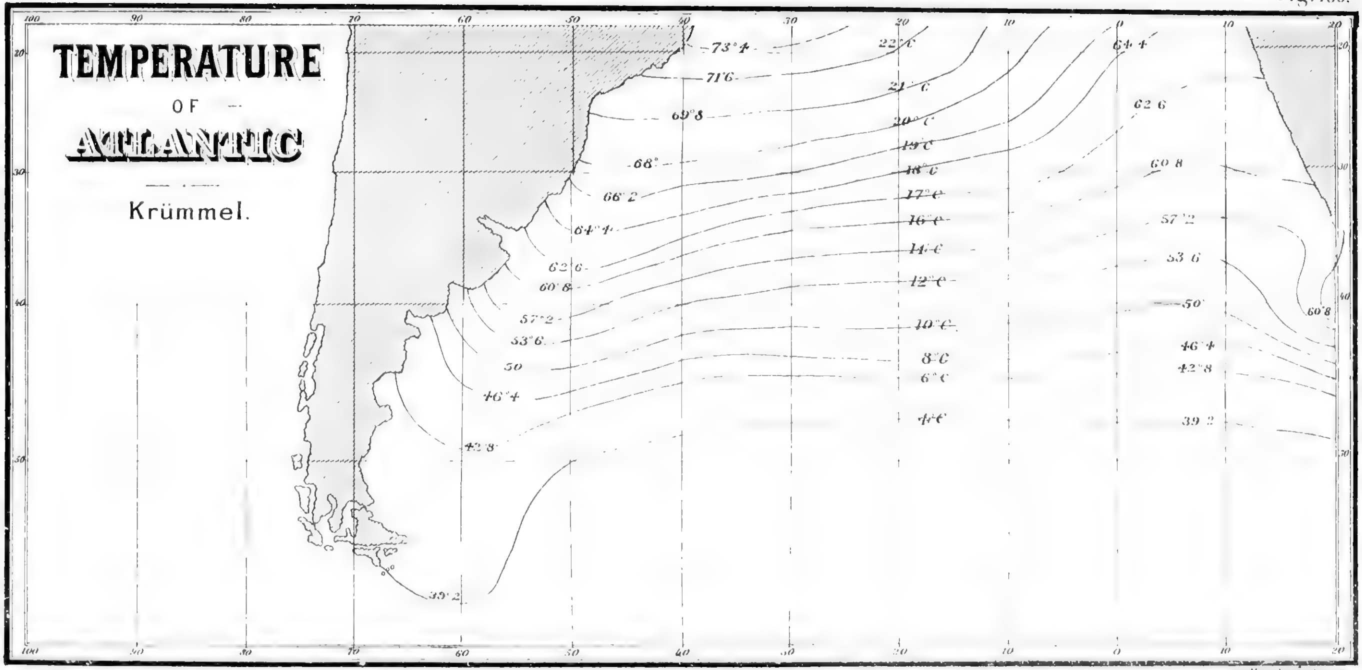
[1] Along the American coast the sudden transition from the green, cold, and more or less turbid water found along the coast and continental shelf, into the deep blue waters of the warm Gulf Stream, is one which has been noticed by all who have passed from the shore seaward. This cold green water, which has such a chilling influence on the climate of the New England States, follows the line of the Atlantic coast of the United States far towards the base of the peninsula of Florida.

present epoch the most marked physical feature of the surface of the globe is its subdivision into a land and an oceanic hemisphere. Thomson, like him, looks upon the oceans as continuous, and has happily styled the Atlantic, the Pacific, and the Indian oceans as great gulfs of the Southern Ocean.

The striking hydrographic character of the North Atlantic is its comparative isolation from the Arctic Ocean; the South Atlantic, on the contrary, is fully open to the circulation of cold water coming from the Antarctic Ocean. (See Fig. 162.) The South Atlantic is shut off from its northern area by the ridge extending from St. Paul's Rocks to Ascension, at a depth of about 2,000 fathoms. The Challenger Ridge runs nearly north and south, leaving a free communication between the Antarctic Ocean and the eastern and western basins of the South Atlantic. The North Atlantic is subdivided into an eastern and western basin at a depth of about 1,500 fathoms by the Dolphin Rise, which follows in a general way the course of the S-shaped Atlantic basin. Ridges separating the Atlantic from the Arctic Ocean extend across Denmark Straits, probably at a shallow depth. From Greenland to Iceland the depth has an average of 500 fathoms; from Iceland to the Færöes, an average of about 300 fathoms; and from there to the Orkneys, of not more than 220 fathoms. From the configuration of the bottom (see Fig. 61), it is evident that a larger amount of cold water must reach the tropics from the antarctic than from the arctic regions,[1] which are shut off from the Atlantic by submarine ridges. Over these, and through the channels of Baffin's Bay, but a limited

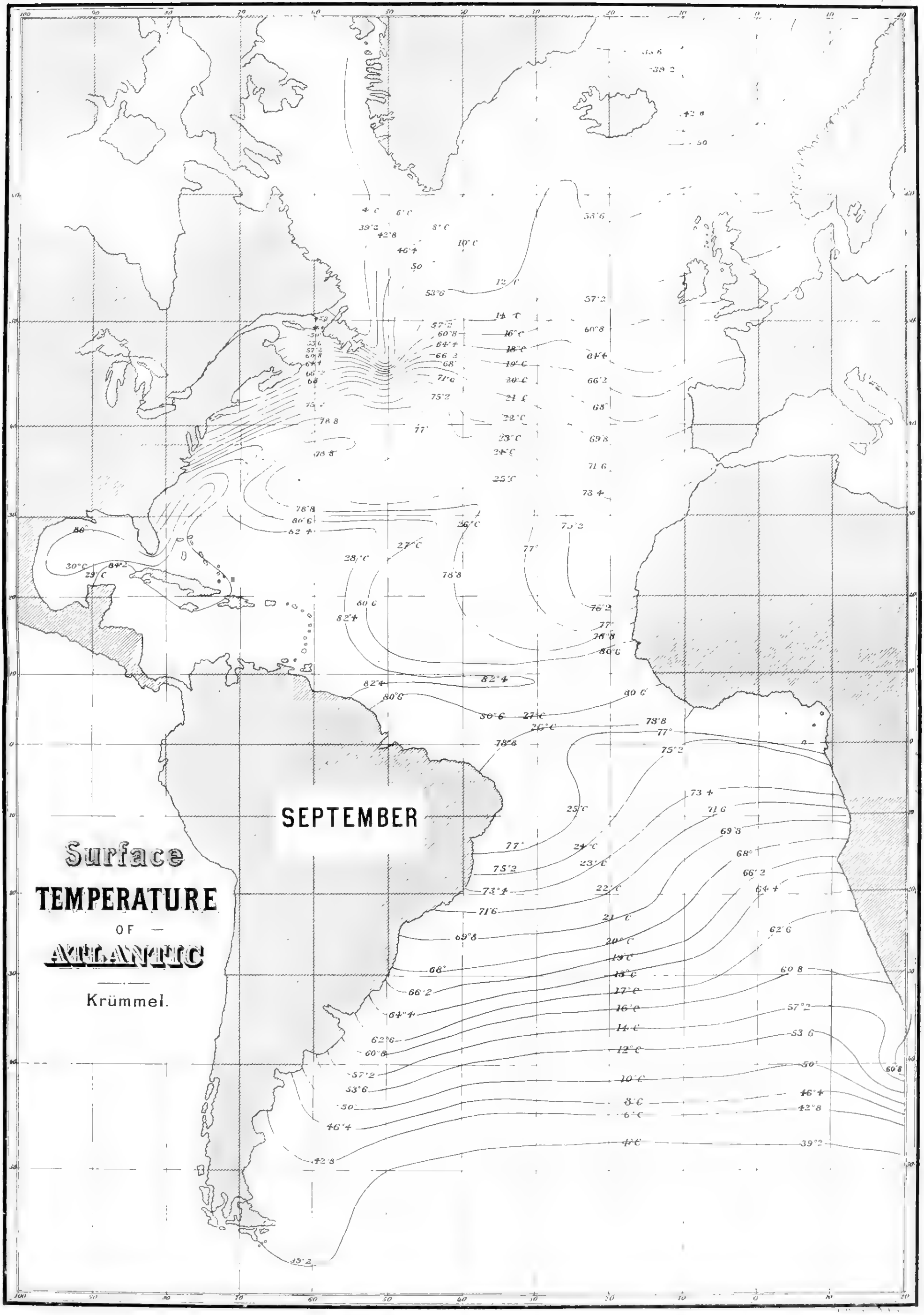
[1] The temperature line run diagonally across the Atlantic from Madeira to Tristan da Cunha by the "Challenger" brings out the remarkably shallow stratum of warm water of that part of the equatorial regions which corresponds to the regions of the tradewinds both north and south of the equator. The temperatures of the belts of water between 200 and 500 fathoms north and south of the line plainly show that the colder water found south of the equator cannot come from the warmer northern belt of the same depth, but must come from the colder belt adjoining the equatorial region. In other words, the cold water may be said to rise towards the surface near the equator; and from the temperature of the two sides of the North Atlantic it is also evident that the supply of cold water flowing from the Antarctic into the Atlantic is greater than that coming from the arctic regions. This vertical circulation, characteristic of the equatorial belt, is insignificant, however, when compared with the great horizontal oceanic currents.

Fig: 169.



TEMPERATURE
OF
ATLANTIC
Krümmel.
73°4
71°6
69°8
68°
66°2
64°4
62°6
60°8
57°2
53°6
50
46°4
42°8
39°2
22°C
21°C
20°C
19°C
18°C
17°C
16°C
14°C
12°C
10°C
8°C
6°C
4°C
64°4
62 6
60 8
57°2
53 6
50°
46°4
42°8
39 2
60°8

Fig: 169.



amount of cold water can find its way south. In the Eastern Atlantic,[1] the principal cooling agent must be the cold water slowly flowing northward from the Antarctic between the Challenger Ridge and Africa.

The shape of the northern extremity of South America, together with the action of the southerly trades, is such as to split the southern equatorial current, and to drive a considerable part of this southern current northward to join the westerly drift which flows to the northward of the Greater Antilles and Bahamas. The phenomena of oceanic circulation in their simplest form are here seen to consist of westerly currents impinging upon continental masses, deflected by them to the northward and eastward, and gradually lost in their polar extension.

There is on the west side of the North Atlantic an immense body of warm water, of which the Gulf Stream forms the western edge, flowing north over a large body of cold water that comes from the poles and flows south. The limits of the line of conflict between these masses are constantly changing, according to the seasons: at one time the colder water from Davis's Straits spreads like a fan near the surface, driving the Gulf Stream to the east;[2] and at another, large masses of warm water extend towards the Færöe Islands, with branches towards Iceland and the coast of Portugal.

An examination of an isothermal chart of the Atlantic (Figs. 168, 169) clearly shows the effect of the isolation of the Northern Atlantic; the area of maximum temperature (82°) extends over a far greater space in the North than in the South Atlantic. The Gulf of Mexico and the Caribbean become greatly superheated in September (to above 86°), the effect of this superheating in conjunction with the westerly equatorial drift being

[1] In the Pacific, the amount of cold water flowing into it through the narrow and shallow Behring's Strait is infinitesimal compared with the mass of cold water creeping northward into the Pacific gulf from the depths of the Southern Ocean.

[2] The direction from which the currents come is plainly shown by the nature of the bottom specimens, made up in part of globigerinæ brought by the warmer southerly surface currents, and in part of northern foraminifera and of volcanic sand derived from Jan Mayen and Spitzbergen. The dividing lines between these deposits may be considered as the boundaries of the arctic current where it passes under the Gulf Stream.

seen clearly in the northerly extension of the isothermal lines. In the South Atlantic,[1] owing in part to the greater regularity in the shape of the basin, the difference in the extension of the isothermal lines is but little marked.

The temperature sections of the "Challenger," from Teneriffe to Sombrero, show remarkably well the great contrast in temperature between the eastern and western basins of the Atlantic, which are separated by the Dolphin Rise. In the eastern basin, the cold water on the bottom is supplied by the indraught from the South Atlantic, while the warmer surface water of the western basin is due to the westerly equatorial currents. We seem, therefore, to have masses of water of different temperatures accumulated at certain points by surface or bottom currents, to be distributed again, either north or south, into the general oceanic circulation, thus restoring the equilibrium disturbed by the unequal distribution of heat and cold on the surface of the ocean.

Another temperature section (Fig. 170) which I shall borrow from the "Challenger" soundings, to complement the work of the "Blake" in the same regions, is that which extends from Halifax to the Bermudas, and thence to St. Thomas. The temperatures observed by these vessels show plainly the path of the warm surface-water, which flows outside of the West India Islands, and joins the Gulf Stream proper, whose waters when united are banked against the cold Labrador current in its course along the American coast.

Undoubtedly, the early observations made upon the temperature of the ocean were defective, owing to the somewhat imperfect instruments at the disposal of the early explorers. Yet they determined the general position of the cold and warm currents of the ocean along our shores. The more systematic work of the officers of the Coast Survey first proved the existence of vast bodies of water, of considerable thickness, and of very different temperatures at corresponding depths, moving in opposite directions. It is to the Coast Survey that we owe the demon-

[1] The parallelism of the lines of temperature is also very marked in the South Pacific, where there are no disturbing influences. See J. J. Wild, "Thalassa," Plate XV., and "Challenger Temperatures."

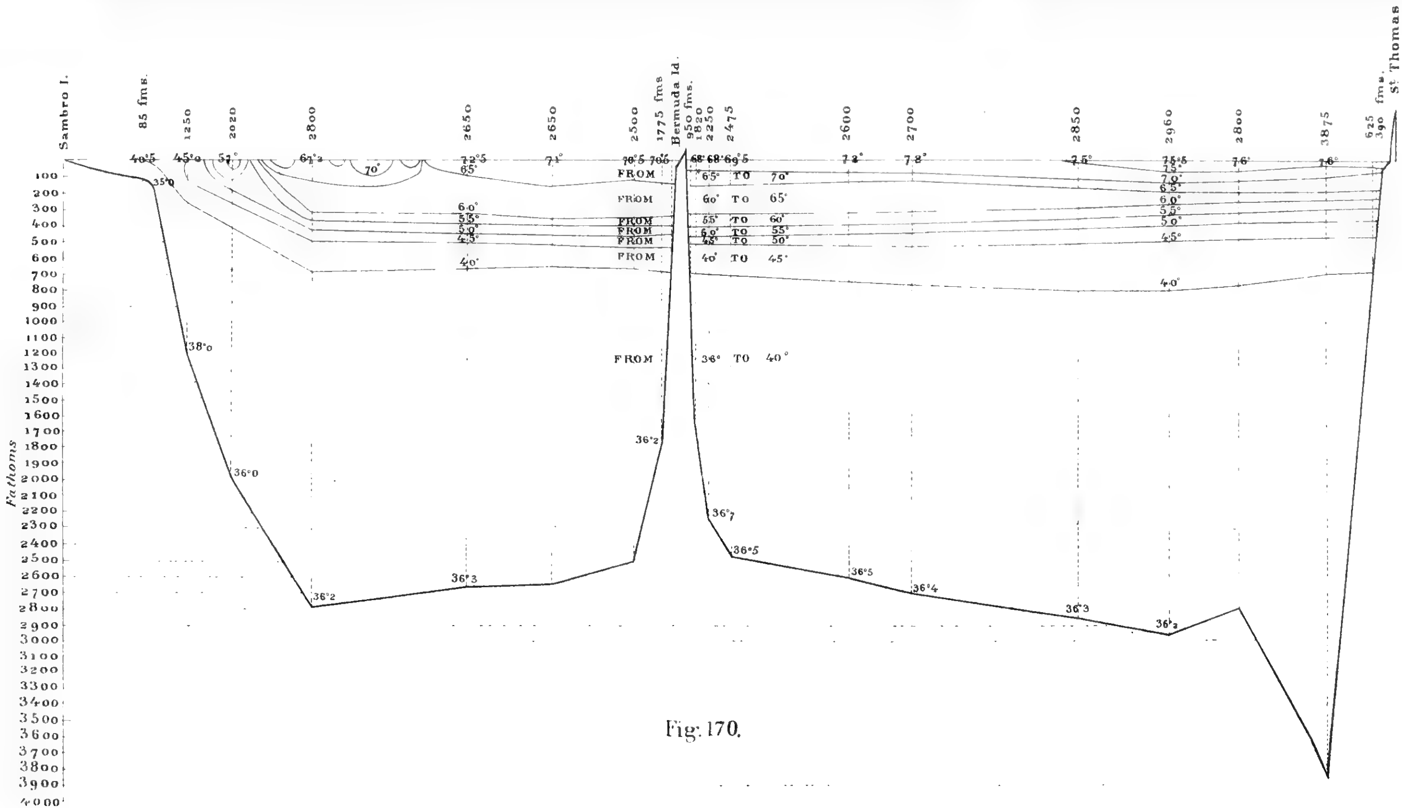

Sambro I.
85 fms.
1250
2020
2800
2650
2650
2500
1775 fms
Bermuda Id.
950 fms.
1820
2250
2475
2600
2700
2850
2960
2800
3875
625
390 fms.
St Thomas
Fathoms
FROM
65° TO 70°
60° TO 65°
55° TO 60°
50° TO 55°
45° TO 50°
40° TO 45°
36° TO 40°

Fig. 170.

stration of the fact that the waters of the polar regions pour into the tropics along the bottom, just as the warmer equatorial waters flow across the temperate zones near the surface, and make their influence felt in the polar regions.

The submarine ridges interrupt the flow of these cold polar waters, and form the so-called closed basins, with a higher bottom temperature than that of the adjoining oceanic basin. The effect of such ridges upon the bottom temperature was first traced by the soundings of the "Porcupine" in the North Atlantic and in the Mediterranean. Subsequently, the "Challenger" discovered several such enclosed seas while sounding in the East Indian Archipelago.

The correctness of these results has been confirmed by the Coast Survey, from soundings in the Caribbean and in the Gulf of Mexico; their bottom temperature (at a depth of over 2,000 fathoms) is exactly that (39½°) of the deepest part of the ridge, at about 800 fathoms, which separates them from the oceanic Atlantic basin, with its temperature of 36° at the depth of 2,000 fathoms.

The presence of thick layers of water having a higher bottom temperature than that of adjoining areas would indicate the presence of ridges isolating these warmer areas from the general deep-sea oceanic circulation. A map of the Atlantic, made entirely with reference to the temperatures, would correspond to a remarkable degree with the topography of the bed of the ocean, and show how and where the breaks in the continuity of the circulation, both for the arctic and antarctic regions, occur in the Atlantic. (See Figs. 140, 142.)

It was not, however, until the Miller-Casella thermometer came into general use for deep-sea investigations that a degree of accuracy before unattainable in oceanic temperature became possible. It soon was a well-recognized fact that as we go deeper the temperature diminishes, and that at great depths the temperature of the ocean is nearly that of freezing. In 1868–69, in the Færöes Channel, the "Porcupine" found a temperature of —1.4° C. at a depth of 640 fathoms, and a temperature of 0° C. at 300 fathoms, this being a southern extension, as was subsequently found, of the deep basin of 1,800 fathoms lying

between Norway and Iceland. The same temperature, 0.9° C., occurs under the equator at a depth of about 2,300 fathoms, while 5° C. is found at a depth of 300 fathoms. As early as 1859 the Coast Survey had recorded in the Straits of Florida a temperature of 40° F. (4.4° C.) at a depth of 300 fathoms, while at the surface the temperature was 80° F. (26.7° C.). Beyond 1,000 fathoms the temperature diminishes very slowly. The "Challenger" also found a temperature somewhat below zero off the Rio de la Plata, at a depth of about 2,900 fathoms.

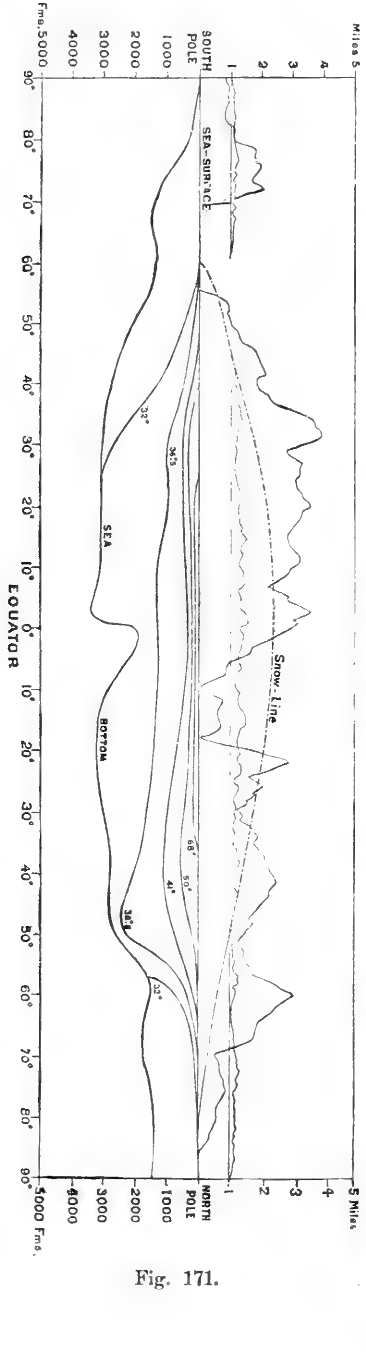


Fig. 171.

The temperature of the oceanic basin depends upon the depth, the latitude, the currents, and the seasons; that of mediterraneans (land-locked seas) is controlled by other causes, which will be more fully discussed when we come to treat of the temperature of the Caribbean and of the Gulf of Mexico. The constants are the depths and latitude, while the disturbing elements are represented by the varying atmospheric and oceanic currents and the seasons.[1] The effects of seasonal differences of temperature do not extend to great depths, yet act with sufficient power greatly to modify the force

[1] Dr. J. J. Wild has given in "Thalassa" an excellent diagram, showing at a glance the general relations of the temperature in the liquid envelopes to the earth's crust. It is here reproduced (Fig. 171), slightly modified.

and volume of the oceanic currents. As a general rule, the temperature diminishes from the surface towards the bottom, a belt limited in depth (about 150 fathoms) alone being subject to variations due to the action of the sun. Below that, the temperature generally decreases with the depth, until we reach the body of water of which the temperature may in general be said to be uniform (about 35°).[1]

As explanations of the oceanic currents, we have, first, the gravitation theory, which looks upon the differences of temperature and of specific gravity of the water at the equator and poles as the prime cause of oceanic circulation; next, Thomson's theory, according to which the difference in evaporation and precipitation between the northern and southern hemispheres causes a consequent heaping up of water in the southern hemisphere, which south of latitude 50° is completely covered by water; thirdly, the theory which attempts to account for the circulation by the *vis inertiæ* of the equatorial waters; and, lastly, the theory which considers the tradewinds and other prevailing winds as the principal causes by which oceanic currents are produced. Franklin, Humboldt, Rennell, Sir John Herschel, and Croll have supported this view of the origin of oceanic currents.

Of course, until the extension of the frictional effect of winds to great depths has actually been measured, the last theory, plausible as it may appear, lacks its final demonstration. It is by no means proved, because there is an apparent connection in time between the periodic variations of the currents and of the tradewinds, that we must seek in the latter the only cause for the existence of the former. The presence of the Guinea Stream, the position of the region of calms in the northern and southern hemispheres, the diminishing force of the tradewinds as we approach the equator, the rise of the colder strata of water to shallower depths in the equatorial than in the temperate regions, are phenomena which the action of the tradewinds alone does not seem to explain. Why may not oceanic circulation, like the

[1] As currents sink as soon as their temperature falls below that of adjoining waters, and as the temperature diminishes from the surface towards the bottom, as well as from the equator to the pole, a combination of these varying elements may produce a somewhat complicated circulation.

movements of our atmosphere, be dependent upon cosmic phenomena, practically independent of any secondary causes, and modified by them within very narrow limits?

The difference in salinity of certain oceanic districts is in itself insufficient to explain oceanic circulation; so that while the secondary causes referred to above are undoubtedly active as producing more or less extensive local circulation, we seem justified in looking upon the differences of temperature of the zones of the ocean as the principal cause of the general oceanic circulation. We may state, in the main, that the density of the ocean water is least at the equator, gradually rises towards the poles, and attains its maximum at 60° of latitude. For the sake of convenience we may call the density of the ocean as one at a depth of 500 fathoms, and consider the strata of water above and below as having a less and a greater density,[1] within very narrow limits; thus the watery envelope is not in a state of equilibrium.

The most important disturbing factors of a uniform distribution of oceanic temperature are the continental masses which lie in the path of the equatorial currents. A comparison of the position of the oceanic isotherms of the North and South Atlantic shows a striking contrast in their course north and south of the equator. A similar comparison between the Atlantic and Pacific brings out plainly the contrast in the course of the isotherms of two oceans, in which the disturbing effect is due in the one to continental masses, and in the other to large groups of oceanic islands.

Perhaps the best example of the unstable equilibrium existing between adjoining oceanic areas is furnished by the heaping up of the waters driven by the tradewinds into the Gulf of Mexico from the Caribbean. The amount of this accumulation has actually been measured by officers of the United States Coast Survey. It gives an additional force at work to keep up the efficiency of the Gulf Stream. The Gulf of Mexico is consid-

[1] Ocean water, at depths exceeding 1,000 fathoms, has a temperature of nearly 35° F., the temperature of greatest density. Should the water become either colder or warmer, it must expand; this it cannot do, on account of the pressure.

ered by Mr. Hilgard as an immense hydrostatic reservoir, rising to the height of more than three feet[1] above the general oceanic level, and from this supply comes the Gulf Stream, which passes out through the Straits of Bemini, the only opening left for its exit.

Arago, Lenz, and Leonardo da Vinci before them, maintained that since the water of the equator was greatly heated and lighter, and attained a higher level, there was a flow of the surface waters towards the poles, a compensation being established by the flow of lower strata from the poles to the equator. The principal features of this thermic theory have of late found their most efficient exponent in Dr. Carpenter. The results of his experiments to prove this theory upon a small scale seemed to show that the cooling of the waters at the pole, and their rapid fall, were a more efficient force than the heating of the water at the equator. Ferrell has called attention to the phenomenon that cold water at the bottom will be swung more to the westward than the water at the top, which will be turned in an easterly direction. As the particles of water ascend, they retain the velocity they had in deeper parts of the ocean, and thus, when reaching either the surface or lesser depths than their original position, they must show themselves as producing a westerly current. This current, deflected by the continental masses as it strikes the east coast, would then be set in motion towards either the north or south pole. At the equator, the water which flows westward from the eastern shores of the continental masses can only be replaced by the compensating waters flowing to it from the north and south. This circulation fairly agrees with the phenomena observed in the South and North Atlantic.

It is interesting to trace the gradual development of our knowledge of the Gulf Stream, and to see how far-reaching has been the influence of the oceanic currents upon the explorations of maritime nations, and the effect these have had in their

[1] By a most careful series of levels, run from Sandy Hook and the mouth of the Mississippi River to St. Louis, it was discovered that the Atlantic Ocean at the first point is forty inches lower than the Gulf of Mexico at the mouth of the Mississippi.

turn on the discovery of America and its settlement.[1] The hardy Norse navigators, nearly five hundred years before Columbus, sailed along the eastern shores of Greenland and America, and extended their voyages possibly as far south as Narragansett Bay, following the Labrador current, which swept them along our eastern shores. It was well known to navigators that upon the western shores of Norway and the northern coast of Great Britain, driftwood of unknown timber and seeds of plants foreign to the temperate zone were occasionally stranded, coming from shores where probably no European had as yet set foot.

The Portuguese navigators, sailing west, came beyond the Canaries to an ocean covered with seaweed (the gulf-weed of the Sargasso Sea), through which none dared to push their way, and the problem of the "Sea of Darkness" remained unsolved until the time of Columbus. He possibly was familiar with the traditions of the voyages of the Norsemen, and undoubtedly had access to more or less accurate information regarding the Atlantic, accumulated previous to his time in the archives of Portugal and Spain, or circulated among the sea-folk of that day, and this information included legends of lands to the west. Columbus started under the full persuasion that he could reach the lands from which the remarkable products brought by the currents had originated. When he came into the region of the northeast trades, and found himself swiftly carried westward, not only by the winds, but also by a current moving in the direction of the trades, his return seemed very hazardous, unless he could strike upon that opposite current, which had borne the trees and seeds to the northern coasts of Europe. Obliged by the trades to take a northerly course on his way home from Hispaniola in 1493, he came upon the region of variable and westerly winds, with a current setting in the same direction. Columbus was thus the first to introduce the circular sailing course which, up to the present day, vessels sailing from the West Indies to Europe are compelled to take. They come before the wind with the trades, make the Windward Islands, and, sailing northward, find their way through the Windward

[1] See Kohl, J. G., Geschichte des Golfstroms und seiner Erforschung, 1868.

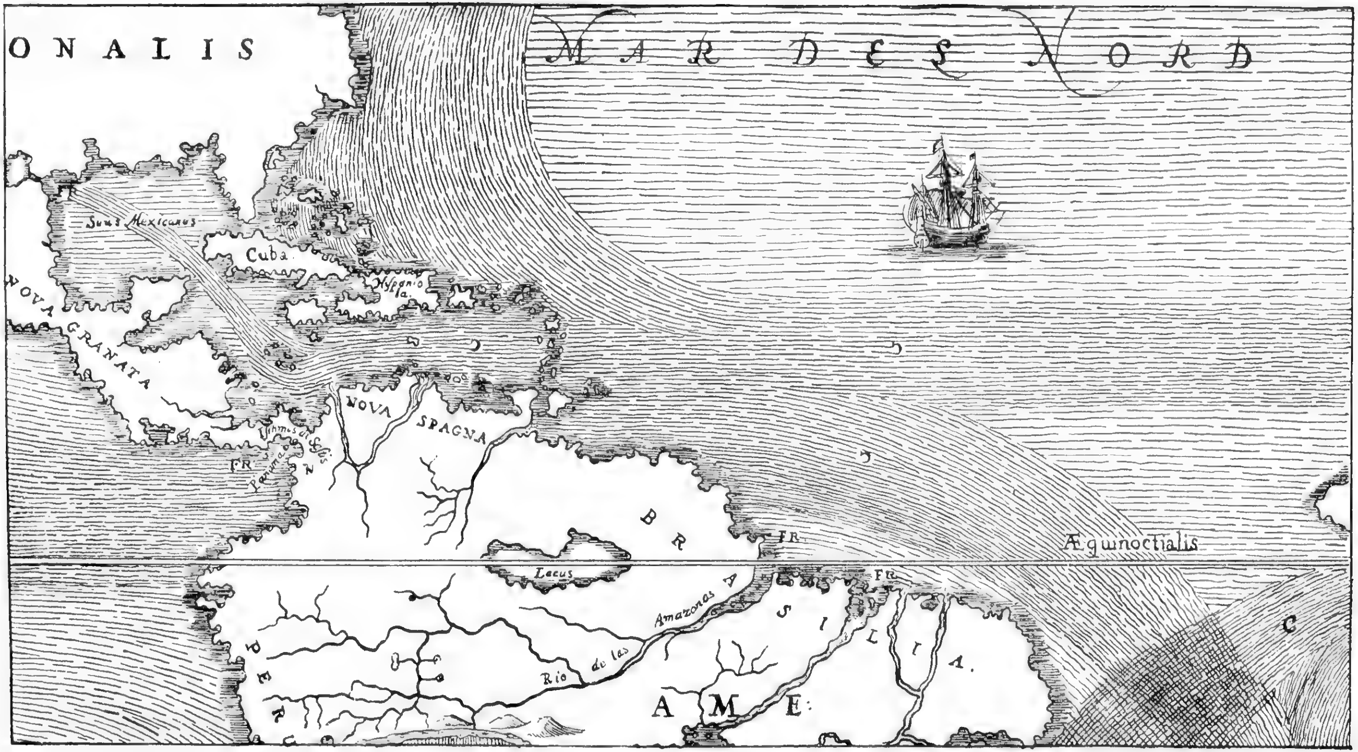


FIG. 172.—OCEANIC CIRCULATION. MAP OF THE 17TH CENTURY.
(FROM ATHANASII KIRCHERI. E. SOC. JESU MUNDUS SUBTERRANEUS EDITIO TERTIA AMSTELODAMI, 1678.)

or the Mona Passage, until they reach the belt of variable and westerly winds, when they steer toward the European shores again.

After reaching the Mexican coast, Columbus, by one of his broad generalizations, practically discovered the Straits of Florida; arguing that it must have an outlet into the Atlantic, and that he would thus escape the tedious voyage in the teeth of the northeast trades, which would be his lot if he attempted to find his way home by the usual route of the Windward or the Mona Passage. In 1519, an expedition inspired by Alaminos was despatched by Garay, Governor of Jamaica, to follow the easterly current running along the northern shores of Cuba. The expedition, however, did not succeed in passing to the eastward of Cape Florida.

An accurate knowledge of the currents and winds enabled the freebooters of the sixteenth century to carry on their depredations with impunity, and their successors, the wreckers of the Florida reefs and Bahamas, made use of their intimate knowledge of the coasts, and of the winds and currents, to obtain commercial advantages, not always by the most honest methods. With the mapping of the reefs by the Coast Survey all this has disappeared, and the lighting of the great highway of the Straits of Florida has reduced to a minimum the dangers of navigation, though the Tortugas are still a favorite resort, even in broad daylight, for old ships properly insured. (Compare Figs. 172 and 34.)

The captain of one of the Spanish vessels was carried south, off the coast of South America, by the current which sweeps from Cape St. Roque along the shores of Brazil, and involuntarily discovered the Brazilian shore current. Though these different currents were known to exist in the Atlantic, the most crude notions of their origin and course prevailed. (Fig. 172.) According to Columbus, at the equator the waters of the ocean moved westward with the heavens above, rolling over the fixed earth as a centre. It was only in the seventeenth century that physicists began to suspect a connection between the currents and the rotation of the earth, a view afterwards maintained by Arago and Humboldt.

The first scientific basis for the exploration of the Gulf Stream was undoubtedly due to Franklin. At the time he was Postmaster-General of the Colonies, his attention was called to the fact that the royal mail packets made much longer passages to and from Europe than the trading vessels of Massachusetts and Rhode Island. On talking the matter over with Captain Folger of Nantucket, he first learned the existence of a strong easterly current, of which the New England captains took advantage in going to Europe, and which they avoided by sailing a northerly course on the home voyage. Folger also called Franklin's attention to the fact that this current was a warm one.[1] He and Dr. Blagden becoming interested in the question, Franklin set out to ascertain the size of the current and its temperature. Soon after, Franklin published the first chart of the Gulf Stream (Fig. 173), for the benefit of navigators, from information obtained from Nantucket whalemen, who were extremely familiar with the Gulf Stream, its course, strength, and extent.

From the time of Franklin until the problem of the Gulf Stream was again attacked, in 1845, by Franklin's descendant, Prof. A. D. Bache of the United States Coast Survey, many ingenious theories were published, but nothing was added to our knowledge of the origin and structure of the Gulf Stream. Humboldt, Arago, and others attempted to trace in the Gulf Stream a secondary effect of the tradewinds, and of the rotation of the earth. The officers of arctic expeditions sent to Spitzbergen did not fail to see the effect of a mass of warm water passing northward, and Von Baer was among the first to consider this body of water as an eastern extension of the Gulf Stream. Meanwhile the arctic explorers of Baffin's Bay and western Greenland found themselves baffled in their efforts to reach high latitudes by the powerful southerly current, carrying with it fields of ice or huge icebergs, which had found their way south below the southern limits of the Banks of Newfoundland, and even beyond the latitude of Cape Cod and Nantucket Shoals.

[1] It was noticed by Lescarbot, in 1605, that far north there was a mass of warm water moving towards the east, and that both north and south of it the water of the Atlantic was cooler.

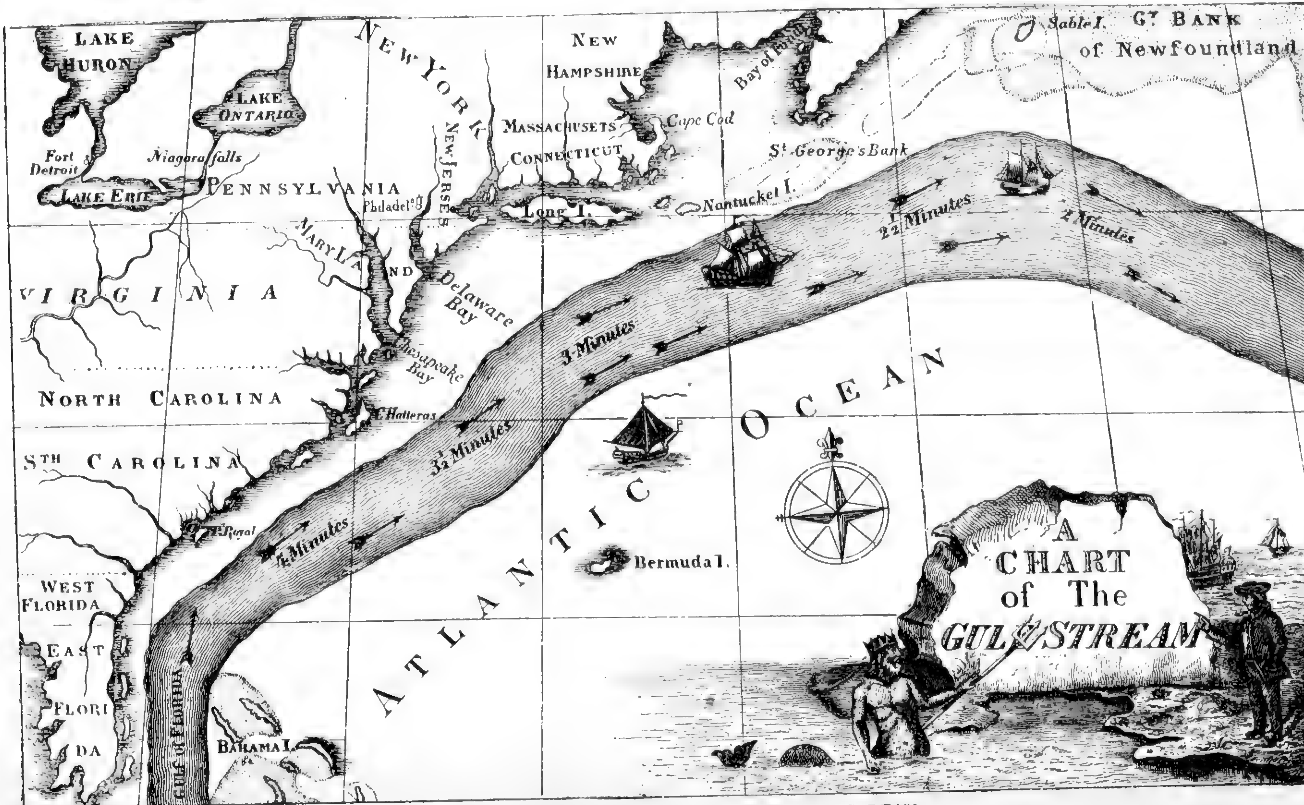


FIG. 173.—FRANKLIN'S CHART OF THE GULF STREAM.

Fig. 174.

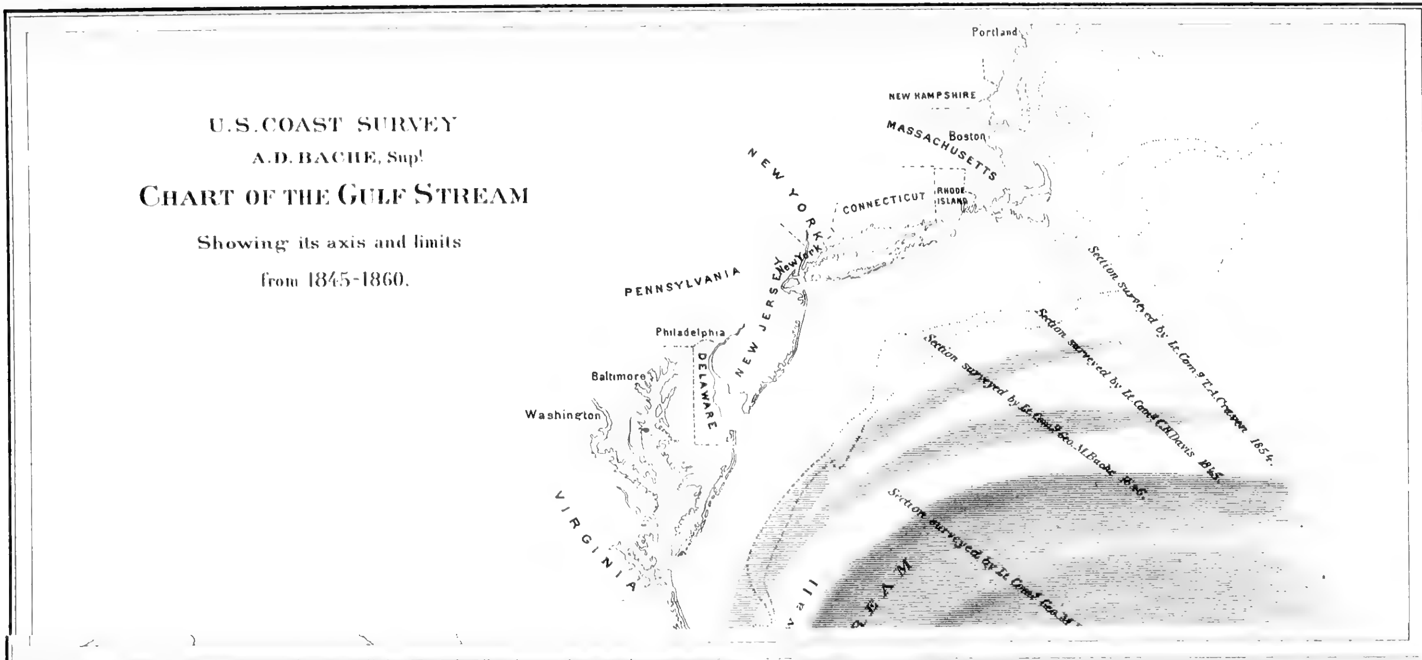
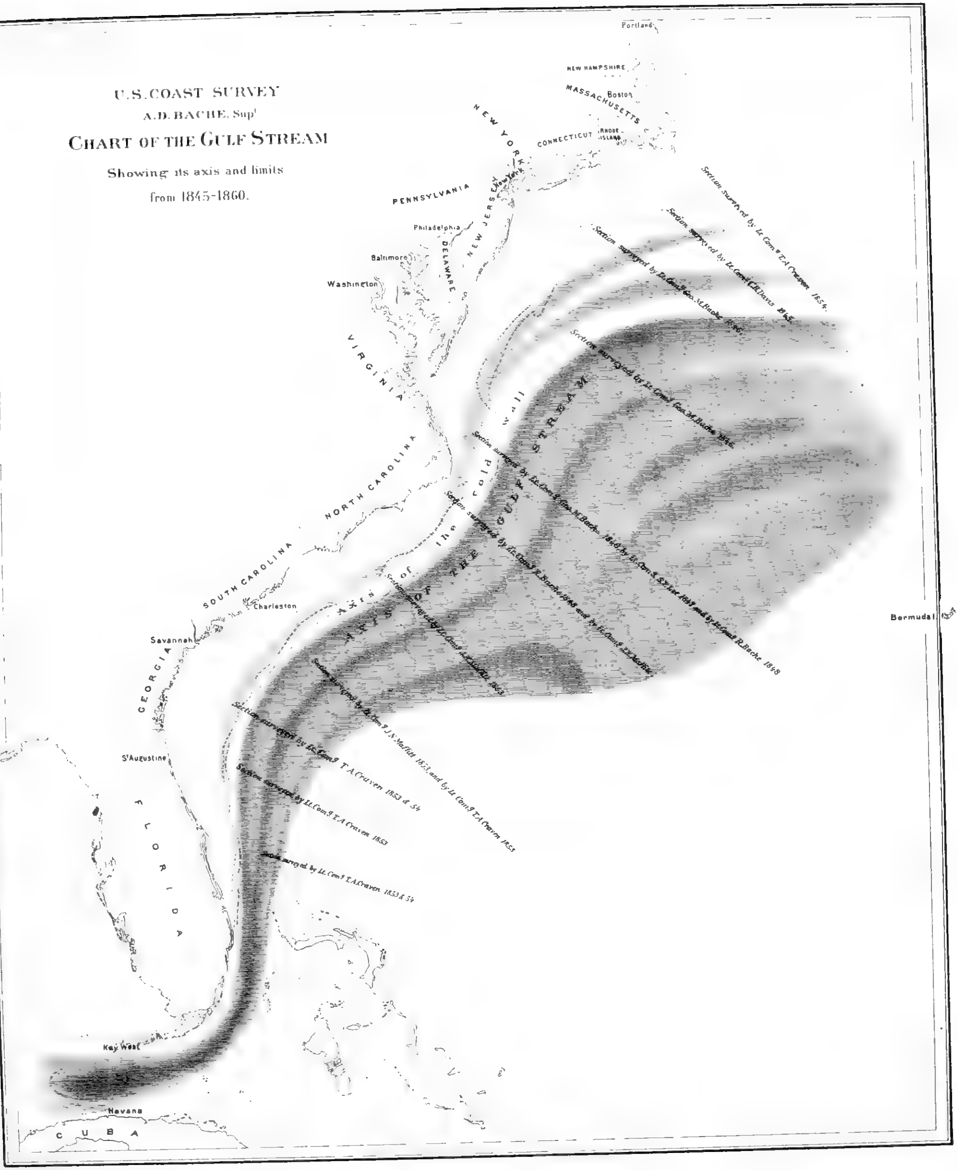

U.S. COAST SURVEY
A.D. BACHE, Supt.
CHART OF THE GULF STREAM
Showing its axis and limits
from 1845-1860.
Portland
NEW HAMPSHIRE
MASSACHUSETTS
Boston
RHODE ISLAND
CONNECTICUT
NEW YORK
New York
NEW JERSEY
PENNSYLVANIA
Philadelphia
DELAWARE
Baltimore
Washington
VIRGINIA
Section surveyed by Lt. Comg. T. A. Craven 1854.
Section surveyed by Lt. Comd. C.H. Davis 1845.
Section surveyed by Lt. Comd. Geo. M. Bache 1846.

Fig. 174.


U.S. COAST SURVEY
A.D. BACHE, Supt
CHART OF THE GULF STREAM
Showing its axis and limits
from 1845-1860.
Portland
NEW HAMPSHIRE
MASSACHUSETTS
Boston
CONNECTICUT
RHODE ISLAND
NEW YORK
New York
PENNSYLVANIA
NEW JERSEY
Philadelphia
DELAWARE
Baltimore
Washington
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
Charleston
Savannah
GEORGIA
St Augustine
FLORIDA
Key West
Havana
CUBA
Bermuda I.
AXIS OF THE GULF STREAM
the cold wall
Section surveyed by Lt. Comg T.A. Craven 1854.
Section surveyed by Lt. Comg C.H. Davis
Section surveyed by Lt. Comg T.A. Craven 1853 & 54
Section surveyed by Lt. Comg T.A. Craven 1853
Section surveyed by Lt. Comg T.A. Craven 1853 & 54

The earlier work of the Coast Survey in its investigations into the structure of the Gulf Stream (1845 to 1860) consisted in making sections across the stream, from the Straits of Bemini as far north as the latitude of Nantucket. From the studies of Craven, Maffitt, Bache, and Davis were developed the so-called cold and warm bands, believed at that time to be the principal characteristic of the Gulf Stream. The accompanying map (Fig. 174), published in 1860 by the Coast Survey, will serve to illustrate the structure of the Gulf Stream as it was then understood; namely, as a succession of belts composed of warm northerly currents flowing side by side with a cold southerly current, or of a cold southerly current which had found its way under the warmer northerly currents. These alternating belts had no definite position, the size of the colder bands and warmer belts being dependent, the one upon the force of the arctic current, the other upon that of the tropical current, increased in breadth and volume beyond the Bahamas by the whole of the warm belt of surface equatorial water, which is deflected northward by the Windward Islands, instead of forcing its way through the passage between the Windward Islands, the Mona and Windward Passages, and the Old Bahama Passage.[1]

[1] Great as is undoubtedly the effect of the Gulf Stream proper (Fig. 175) in increasing the temperature of the water in northern latitudes subject to its influence,

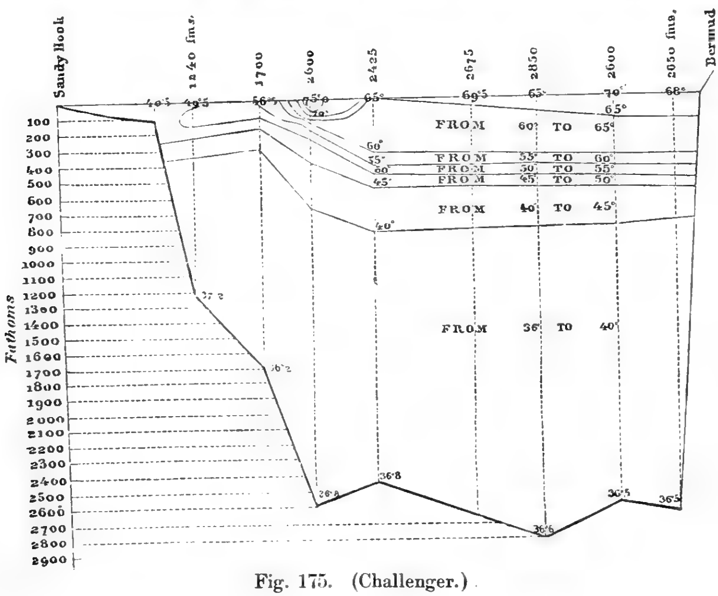


Fig. 175. (Challenger.)

Commander Bartlett found no warm or cold bands, no distinct cold wall, and no bifurcations in the surface waters till he came off Hatteras. Near the shore, the current was greatly influenced by winds. The work of the "Blake" seems to show that the cold bands so called, which figure so largely in all early descriptions of the Gulf Stream, have no regularity, and only represent at any given moment the unceasing conflict going on between layers of water of different velocities and of different temperatures. Such a conflict is perhaps the well-known rip we encountered off Charleston, which may be caused by a struggle between portions of the Labrador current passing under the Gulf Stream. As the isotherms rise and fall with the irregularities of the bottom, where water accumulates or piles against ridges, hot and cold bands may be flowing one above the other. We need, however, more prolonged observations to show how far below the surface these bands extend. Commander Bartlett from the last Coast Survey investigations under his direction is inclined to consider the cold bands of the Gulf Stream as quite superficial.[1]

A cold current striking against a warmer stream that is flowing in the opposite direction may split it into more or less marked hot and cold bands. Bands similar to those of the Gulf Stream were observed by the "Challenger" in the Agulhas current off the Cape of Good Hope, and off Japan in the Kuro-Siwo.

It is of course difficult to ascertain the part taken by the

we must not forget to add to it that of the greater mass of heated water which is forced north, and finds its way to the northernmost shores of Siberia, losing in its passage the heat it has accumulated within the tropics. So that, while we cannot say that the Gulf Stream has disappeared, and has been replaced off the Banks of Newfoundland by the equatorial drift, neither can we attribute to the Atlantic drift alone the masses of warm water found in the basin of the northern part of the North Atlantic. (See Figs. 170 and 175.)

[1] In sailing from Halifax to the Bermudas, Sir Wyville Thomson speaks of passing alternate belts of cold and warm water. Early in the morning of the 22d of May, the surface water was of a temperature of 17° C.; at midnight it had fallen to 12° C., to rise again half an hour later to over 15° C. Thus, from the time the "Challenger" left Halifax with a surface temperature of 4° C., gradually rising to 10° C. until she encountered the Gulf Stream proper, marked by a rapid rise of temperature, she passed through alternate belts of warm and cooler surface waters varying between 18° C. and 23° C.

tradewinds in originating the oceanic circulation of the Atlantic. That winds blowing steadily from one quarter give rise to powerful currents is well known, and it is not difficult to imagine the prominent part the trades must play in setting in motion, in a southwesterly and a northwesterly direction, the mass of water over which they sweep so persistently on each side of the equator.

The change of currents in the Indian Ocean due to the shifting of the monsoons is well known. How far below the surface this action of the winds reaches, is another question.[1] Theoretically it has been calculated by Zoeppritz that one hundred thousand years is ample time to allow the friction of the particles to extend from the surface to the bottom, say to two thousand fathoms, were the winds to blow without intermission in one direction during that time, with the average power they are known to possess.[2]

We may imagine the whole of the mass of the Atlantic within the belt of the tradewinds to be moving in a westerly direction, and impinging upon the continental slope of South America[3] and upon the Windward Islands; at which point it is deflected either in a southerly or northerly direction, or forces its way into the Caribbean. In our present state of knowledge it is difficult to trace the path of the equatorial water as it is forced into the eastern Caribbean. Commander Bartlett supposes that it is warmed in the Caribbean by circulating round the whole basin. The water which is swept into the Caribbean by the tradewinds through the passages between the Windward Islands, and being then driven into the Old Bahama Channel funnel,

[1] The movement arising from the action of the winds on the surface is transmitted by friction from one layer to another, and communicates the velocity of the upper particles to the underlying layers in succession. If this is continued long enough, the velocity of the lowest layers will equal within a fraction that of the upper layer.

[2] It is therefore possible that currents, which owe their existence to causes that have been modified to a certain extent, should still exist in the ocean long after the conditions producing them (acting from the surface) have ceased to be effective by any break of continuity due to the interposition of islands or of banks in the track of oceanic currents.

[3] Did the Gulf Stream not meet continental masses, it would simply expand north and south, losing its initial velocity, and gradually cool down towards the poles; the cold penetrating all the deeper portions of the ocean, just as we find it reaching the higher summits that rise above the line of perpetual snow.

flows through the Windward Passage, represents a far greater mass than that which can find its way into the Gulf of Mexico through the Straits of Yucatan, or that of the stream flowing north through the Straits of Bemini. This is the actual Gulf Stream, a body of superheated water filling the whole straits; it has an average depth of about three hundred and fifty fathoms, and a velocity extending to the bottom of at least three and a half miles an hour.[1]

The section of the Yucatan Channel is too small to allow for an outflow equal to the inflow into the Caribbean,[2] so that, after the trades have ceased to force the equatorial water into the Caribbean basins, it must remain there a considerable length of time before it passes into the Gulf of Mexico, where, owing to similar differences between the rate of inflow and outflow, the water must become still more superheated.

We must therefore consider the Gulf Stream proper, as it emerges from the Straits of Bemini, as an immense body of superheated water, retaining an initial velocity which originated in lower latitudes; then losing both its velocity and its heat on its way north.[3] (See Fig. 176.)

The Straits of Florida have a width of about forty-eight miles between Jupiter Inlet and Memory Rock; the greatest depth is 439 fathoms, and the cross-section 430,000,000 square feet. At three knots the delivery would be, as calculated by Commander Bartlett, about 436,000,000,000,000 tons a day, — an amount of warm water far less than that we find over the North Atlantic,

[1] Current observations taken by Mitchell off the coast of Cuba, in the deep part of the Gulf Stream, show that it has a nearly uniform and constant velocity for a depth of 600 fathoms, although the temperature varies 40° F.

[2] A part of this water emerges again at a higher temperature between Guadeloupe and Hayti, and joins that portion of the equatorial current which finds its way into the Windward Passage. This increased temperature may be due to its passing over shoals and banks at the northeastern end of the eastern basin of the Caribbean.

[3] Between Halifax and the Bermudas the section of the Gulf Stream observed by the "Challenger" was cooled 1° C., as compared with that of the Bermudas to New York. The Gulf Stream retains its heat as a surface current as long as the temperature is sufficiently high to make it lighter than the surrounding water. Its greater salinity at last causes it to sink below the comparatively fresher water of northern latitudes. Similarly, the arctic current, when it reaches a certain latitude along our eastern coast, sinks from its greater specific gravity below the warmer surface currents, and continues its way south as an undercurrent of cold water.

which, as has been shown, is derived from the western set of the equatorial current joining the Gulf Stream in its way towards the European shores.[1] (See Figs. 170–175.)

Commander Bartlett thus describes the general course of the Gulf Stream: —

"The Gulf Stream has for its western bank the one-hundred-fathom curve as far as Cape Hatteras. It has a depth of 400 fathoms as far as Charleston, where it is reduced to 300 fathoms; but the Arctic current has for its western bank the one-thousand-fathom curve, which is quite close to shoal water from the George's Bank to Hatteras.

"The average surface temperature in the axis of the Stream rarely exceeded 83° F. in June and July. On one or two occasions the thermometer read as high as 86°, and once 89°; but it was at high noon in a dead calm. The temperature at five fathoms did not range above the average of 81½°.

"The increase of temperature of the surface was found as we entered the current. . . .

"The surface temperatures did not indicate a cold wall inside of the Stream, and the water inside of the one-hundred-fathom line to the shore seemed to be an overflow of the Stream, as the temperatures to five, ten, and fifteen fathoms were nearly as high as those found in the Stream.

"The temperatures at the bottom in the Stream, at corresponding depths, were the same as those found in the Windward Passage, and in the course of the current to the Yucatan Passage. The average bottom temperature at 400 fathoms was 45°, and, as off Charleston,[2] in 300 fathoms, 53°. The temperature at 300 fathoms, off the George's

[1] It might, perhaps, be advisable to distinguish between the eastern extension of the Gulf Stream combined with the Atlantic drift, and the Gulf Stream proper, understanding by the latter the water which passes through the Florida Straits. This has been called by Petermann the Florida Stream; and the name of Gulf Stream he has applied to the immense body of warm water which superheats the basin of the Eastern Atlantic to the eastward of 45° W. Long. There seems to be no reason for changing the name of the Gulf Stream because so many other liberties have been taken with it. We should retain the original name, limiting it to the Florida Stream coming from the Gulf of Mexico, and apply to its eastern extension, in connection with the Atlantic easterly drift, some new name, such as the Equatorial Drift, or the Caribbean Stream.

[2] About eighty miles from Charleston a line was run parallel to the coast, along the axis of the Gulf Stream.

Depth in Fathoms.	Surface Temperature.	Temperature at 2 fathoms.	Bottom Temperature.	Nature of Bottom.
257	83°	83°	50°	No specimen.
291	83°	83.5°	45°	Fine sand.
274	83.5°	83.5°	44.5°	Coarse sand.
288	87.5°	83.5°	45°	No specimen.
265	84°	83.5°	45°	Coarse sand.

Bank, was found in July to be 40°; and this last was the temperature that we found at the same depth just north of Hatteras and the Gulf Stream.

"I have stated that the surface temperatures did not show a cold wall inside the Stream; but the bottom temperatures give a narrow cold section close to the one-hundred-fathom curve all along the course of the Stream from Hatteras to Florida. Soon after leaving the Straits of Florida there is a division of the Stream shown by the bottom temperatures, part following the coast, and the remainder branching off to the eastward. . . .

"We found that three knots was a general average to allow for the whole stream. This would give a greater velocity at some central point. Between the Bahamas and Florida the average was exactly three miles per hour; but for a distance of fifteen miles in the axis of the Stream it was as high as 5.4 miles per hour. To the northward of the Bahama Banks, and to the eastward of the Stream, there was a slight current setting southeast. We found the direction of the current in the Stream very much affected by the wind, — sometimes inclining it to the east, then to the west.[1]

"In the latter part of June, 1881, we were hove to, some fifty miles east of the Gulf Stream, off Charleston, where we experienced a current of three miles per hour, setting southeast; wind blowing a gale from southwest.[2]

"The sudden rise of the plateau off Charleston, together probably with the meeting of the arctic and warm currents, creates a remarkable disturbance at this point. . . .

"We crossed the Stream six times in this locality, under conditions of weather from a calm to a strong breeze, and always crossed, near the centre of the Stream, bands of rippling water several miles in width. It is very like the rip at the entrance to Long Island Sound."

The Gulf Stream flows at the rate of about one fourth of a mile an hour through the Yucatan Channel, which is ninety miles wide, and over one thousand fathoms deep. Through the

[1] Inshore of the Gulf Stream, though a southerly current was distinctly traced inside the one-hundred-fathom line, yet the temperature of the water towards the shore was but little cooler than that of the Stream itself; the same is found to be the case if we examine the temperature sections of the eastern edge of the Gulf Stream. The Stream itself seems to be mainly characterized by its velocity and by its color.

[2] On the southern side of the Gulf Stream Commander Bartlett observed immense quantities of gulf-weed; this is also blown into Narragansett Bay in considerable quantities, covered with clusters of floating barnacles.

Fig: 176.

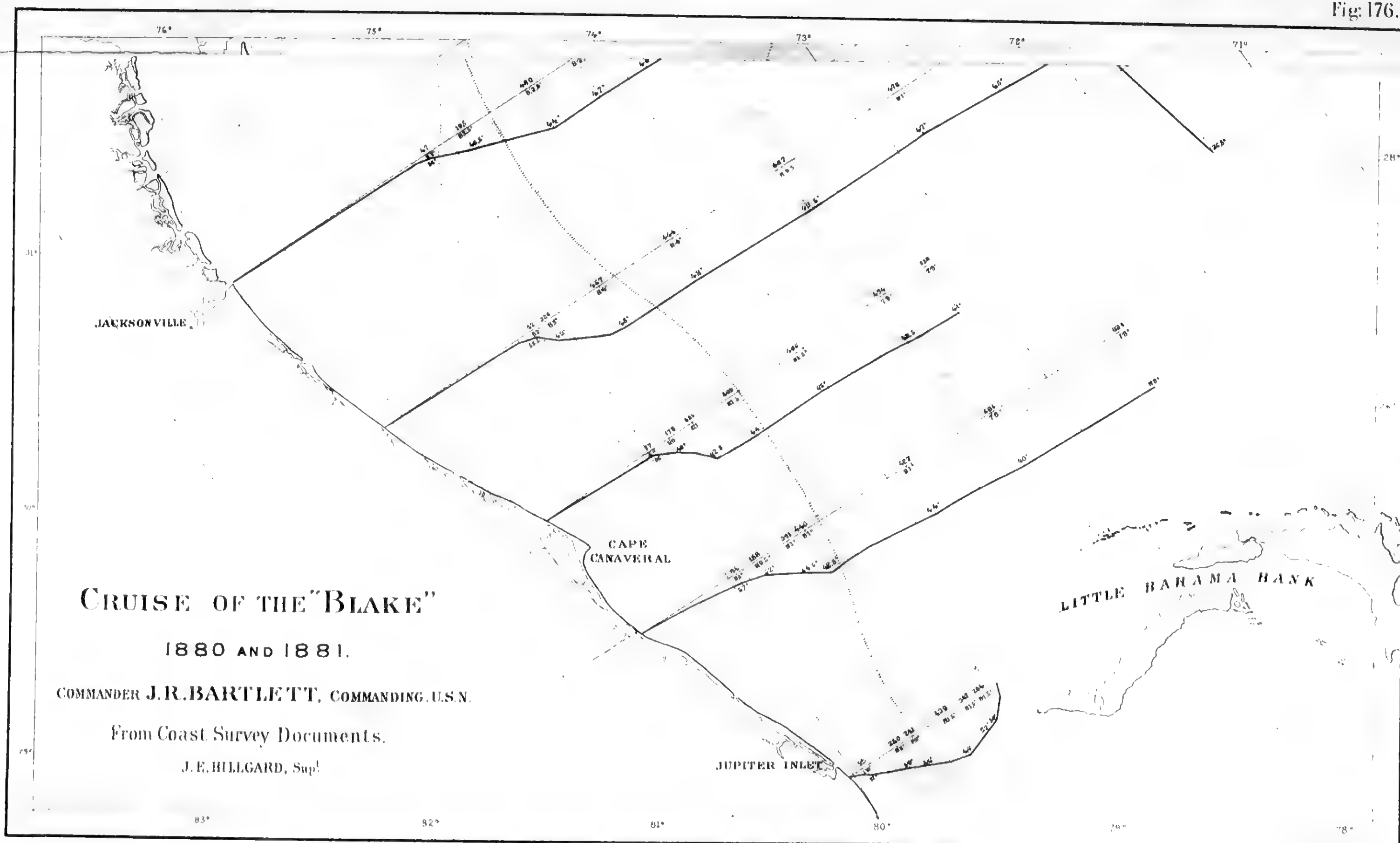

JACKSONVILLE
CAPE CANAVERAL
JUPITER INLET
LITTLE BAHAMA BANK
CRUISE OF THE "BLAKE"
1880 AND 1881.
COMMANDER J.R.BARTLETT, COMMANDING U.S.N.
From Coast Survey Documents.
J.E.HILLGARD, Supt.

Fig 176


ALBEMARLE SOUND
CAPE HATTERAS
100 fathom curve
Axis of the Gulf Stream
CAPE FEAR
CHARLESTON
SAVANNAH
JACKSONVILLE
CAPE CANAVERAL
JUPITER INLET
LITTLE BAHAMA BANK
CRUISE OF THE "BLAKE"
1880 AND 1881.
COMMANDER J.R.BARTLETT, COMMANDING, U.S.N.
From Coast Survey Documents
J.E. HILGARD, Supt

Straits of Bemini it has a velocity of from four to five knots, a width of fifty miles, and an average depth of three hundred and fifty fathoms. This velocity rapidly decreases as we go north. (Fig. 176.) Off St. Augustine it is rarely more than four miles; from there to New York it decreases to two and a half miles per hour; off the Banks of Newfoundland it is reduced to one and a half or two miles; and at a distance of three hundred miles to the eastward the velocity of the Gulf Stream, which has constantly been spreading out fan-shaped, is scarcely perceptible.

As far as the current observations of the "Blake" may be trusted, they indicate a greater speed in the axis of the Gulf Stream than along its edges, — a velocity varying between two miles an hour, or even less, and fully five miles. The width of the Stream off the east coast south of Hatteras varies from fifty to nearly one hundred miles.

The observations of the "Blake" show that the bottom of the Gulf Stream along the Blake Plateau is swept clean of slime and ooze, and is nearly barren of animal life.

XII.

SUBMARINE DEPOSITS.

THE explorations of the "Blake" during my stay on board did not extend to oceanic basins far from land, but were limited to the investigation of enclosed seas like the Caribbean and Gulf of Mexico, and of the continental edges of a part of the western basin of the North Atlantic. The "Blake" subsequently sounded the oceanic basin to the west of the Bermudas and north of the Windward Islands. I have myself had no opportunity of seeing on the spot the deposits characteristic of a true oceanic area, and have supplemented the results of the "Blake" by those obtained by the "Challenger" and "Tuscarora" in the great oceanic basins.

The character of the bottom specimens near shore differs very materially from that of deposits brought from corresponding depths in the open ocean. Along the Atlantic shores of the United States, these deposits are primarily affected by the geological structure of the mainland, the width of the continental shelf, the direction of the currents and of the prevailing winds, and the presence or absence of rivers. Within the Caribbean and on the oceanic face of the Greater and Lesser Antilles, the presence of an equatorial current, of the tradewinds, of volcanic rocks, and of extensive limestone plateaux, introduces conditions which differ radically from those operating upon the Atlantic coast. In the Gulf of Mexico, although the distance from shore of the central part of the basin is often very considerable, still the character of the bottom deposits is always somewhat affected by its peculiar physical conditions. And nowhere in the Gulf or the Caribbean, or around the Atlantic slope of the United States, do we find any ooze strictly comparable to that of the open oceanic basins.

The constant working over of the loose material by the waves and currents along every part of the coast line is repeated on a larger scale upon the continental shelf of our Atlantic coast. There the results depend, not only on the nature of the materials of the adjoining coast, but also upon the distance from shore, the depth, the slope of the coast, and the character of the bottom, and of the animals and plants living upon it and in the surface waters.

Mr. Murray [1] of the "Challenger" has paid special attention to the bottom deposits, and we draw freely from his papers in the sketch which we give of the various kinds of bottoms he has recognized, as well as of the interesting views he holds on the nature and origin of oceanic deposits. The subject as a whole was first treated by Mr. Murray, to whom in connection with the Abbé Renard we owe a connected sketch of deep-sea formations.

Our knowledge of marine deposits was formerly limited to those of shallow waters. Attention was paid only to specimens which could be collected by the Stellwagen cup, commonly used for inshore hydrographic purposes. Our older charts contained at best only meagre information regarding the most characteristic shore deposits. From the study of these we were able to obtain a general idea of the nature of deposits on the inshore plateau of the continental shelf, derived from materials constantly subjected under very special conditions to the action of the tides, waves, and currents. We could of course find no clue to the conditions under which deposits were taking place in the immense abyssal basins, thousands of miles in extent, that occupy certain areas both in the Pacific and Atlantic, far away from any continental mass. As soon, however, as samples of the bottom were obtained from these great depths, a new chapter was opened in thalassography. An examination of these samples has given us the first comprehensive sketch of deep-sea deposits.

[1] Mr. John Murray, to whom the specimens of bottom deposits collected by the "Blake" were sent for examination, has described in detail some typical specimens from the coast between the Gulf of Maine and Cape Hatteras; between Cape Hatteras and Lat. 31° 48′ N.; from the shores of the Greater and Lesser Antilles; and, finally, from the Gulf of Mexico and Straits of Florida. Analyses of the characteristic deposits will be found in the Bulletin of the Museum, Vol. X. No. 2.

The specimens examined are procured by the collecting cylinders of sounding-machines, and the results are corrected to a certain degree by those obtained from the larger masses of material brought up by the dredge or trawl. The bottom deposits collected by the latter instruments may have had some of their smaller particles washed out on their way to the surface, and they are also exposed on their upward journey to different physical conditions. This may affect their relative chemical composition, so that in examining these larger masses care should be taken to consider them merely as indicating the nature of the bottom deposits. Our ultimate knowledge of these deposits is derived from the most careful microscopical investigation, supplemented by chemical analyses of the organic and inorganic substances which they contain. The presence of amorphous mineral matter, of calcareous shells and other skeletons of invertebrates, and of minute organic particles, greatly complicates this examination. In addition, all these particles have been subjected to the action of many agencies, chemical and physical, the nature of which is not well understood, and have had their original characters more or less modified by these agencies.

Fig. 177. — Spherule of Bronzite from 3,500 fathoms, Central Pacific. (Chall.) $\frac{25}{1}$.

Marine deposits are composed of organic and inorganic particles, derived, on the one hand, from the rocks of the continental masses and oceanic islands, and, on the other, from the remains of the animals and plants living in the surface waters and on the floor of the ocean. There are, however, in some of the deposits of very deep water far from continents certain minute metallic and magnetic spherules (Figs. 177, 178, 179), and other small fragments, called *chondres*, which Mr. Murray has shown to be of cosmic origin, — the dust of falling stars and meteorites accumulating on the bed of the ocean in those places where the rate of deposition is at the minimum.

The various kinds of deep-sea deposits are named after the fragments or organisms predominating in each, or so numerous as to be characteristic.

The deposits found in more or less close proximity to continental shores are chiefly made up of the *débris* brought down by rivers or torn away from the adjoining coasts. These are

Fig. 178. — Black Spherule with metallic nucleus. $\frac{20}{1}$. (Chall.) 3,150 fathoms, Atlantic. External coating removed to show the metallic nucleus. (Chall.)

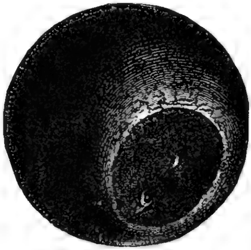


Fig. 179. — Spherule covered with a coating of black shining magnetite. The most common shape showing the depression found at the surface. $\frac{20}{1}$. 2,375 fathoms, Pacific. (Chall.)

called generally terrigenous deposits, and consist of quartz sands, marls, blue, red, and green muds, and greensands. Around the shores of volcanic islands and coral islands, the deposits are volcanic muds and sands, and coral muds and sands.

Masses of rock, or huge boulders, but little altered, are found close inshore, near the spot from which they originated. Farther out, these are replaced by coarse shingle and gravel, merging gradually, in the progress seaward, into the finer material on the bottom.

The fragments of quartz, feldspars, mica, together with fragments of gneiss, granite, mica schist, and other ancient and stratified rocks, which are very abundant in the deposits along continental coasts, become gradually smaller in size and fewer in number as we proceed towards the deeper and more distant parts of the oceanic basins, when they become no longer recognizable in the deposits, but form an impalpable ooze; the case, however, is different with those regions of the ocean which are affected by floating ice and icebergs,[1] and certain other

[1] Along our coasts, icebergs loaded with boulders and detritus brought from northern regions drift south as far as latitude 36°, and distribute foreign material

regions where the dust from deserts is blown a long distance to sea.

Where great rivers enter the ocean, the finer material is carried out to a much longer distance than happens along coasts where there are but small rivers. The greensands, which owe their peculiar character to the presence of glauconitic grains and glauconitic casts of foraminifera and other organisms, are generally found along continental coasts where the fine silt from rivers is not very abundant, as, for instance, off the Shetland Islands, off the Cape of Good Hope, and off Japan, Australia, and some parts of the east coast of North America. It is within the limited area in proximity to the continents, and occupied by terrigenous deposits that the varied physical conditions are found upon which our zoögeographical divisions are based.

The deposits now forming at the bottom of the great ocean

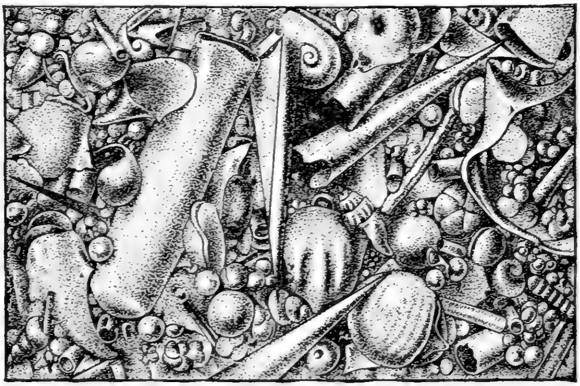


Fig. 180. — Pteropod ooze. $\frac{4}{1}$. (Murray and Renard.)

basins far from land are made up of organic oozes or red clay. The organic oozes derive their chief characteristic from the presence of immense numbers of dead shells, skeletons, and frustules of pelagic organisms, which have fallen from the surface waters. In the pteropod and globigerina oozes, the remains of these organisms consist of carbonate of lime, which occasionally

upon the floor of the Northwestern Atlantic. Thus boulders and fragments of shore rocks become mixed with oceanic deposits.

comprise over ninety per cent of the deposit. A pteropod ooze (Fig. 180) is met with in depths of less than two thousand fathoms in the tropics, and is very largely made up of pteropod and

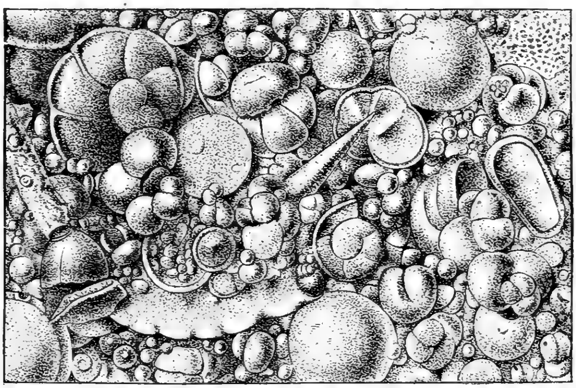


Fig. 181. — Globigerina ooze. $\frac{20}{1}$. (Murray and Renard.)

heteropod shells, as Hyalea, Styliola, Spirialis, Atlanta, etc. These shells also exist in considerable numbers in the deposits around oceanic and other islands. A globigerina ooze (Fig. 181) has a much wider distribution in latitude than a pteropod ooze, and is met with in deeper water. It consists of vast numbers of the shells of various species of foraminifera.[1] Some of the species predominate in one locality, and some in another. There are a large number of other species of foraminifera in the deposits, but those named make up more than ninety per cent of those present. They live in the surface waters, and their dead shells accumulate on the bottom, while the other species live on the bottom itself. (Fig. 182.)

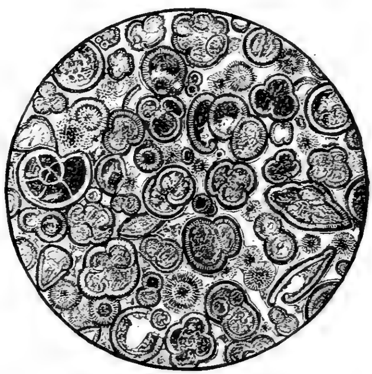


Fig. 182. — Globigerina slab, off Alligator Reef. 147 fathoms. $\frac{15}{1}$.

[1] They are *Pulvinulina Menardii, canariensis, crassa, Micheliniana*, and *tumida ; Pullenia obliquiloculata ; Sphæroidina dehiscens ; Candeina nitida ; Hastigerina Murrayi* and *pelagica ; Orbulina universa ; Globigerina bulloides, æquilateralis, saculifera (hirsuta), dubia, rubra, conglobata*, and *inflata*.

In radiolarian (Fig. 183) and diatom (Fig. 184) oozes the deposits consist of siliceous skeletons and frustules of surface

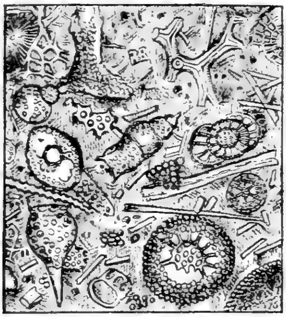


Fig. 183. — Radiolarian ooze (Murray). $\frac{75}{1}$.

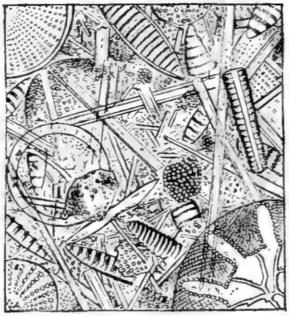


Fig. 184. — Diatom ooze (Murray). $\frac{150}{1}$.

organisms, which have likewise fallen from the surface waters. A radiolarian ooze has hitherto been met with only in the deepest waters of the Western and Central Pacific, and diatom ooze appears to be confined to the Southern Ocean, a little north of the Antarctic Circle.

Thus it will be seen that the character of a marine deposit is largely determined by its distance from land, and again by the nature of the organisms living in the surface waters. The dead shells of pteropods, of foraminifers, of radiolarians, and of diatoms are heaped up on the bottom, some in one part of the ocean, some in another; and as no other materials reach these distant regions to cover them, they form characteristic deposits. Depth is, however, an important factor in reference to the composition of a deposit in any locality. There seems to be now no doubt that the whole of the carbonate of lime shells, such as those of mollusks and foraminifers, are entirely removed by solution in very deep water during their fall from the surface to the bottom, or immediately after reaching the bottom. It is found that, with increasing depth, the pteropod and heteropod shells are the first to disappear from deposits, then the more delicate surface foraminifera, and finally the larger and heavier ones. It is likewise observed, that the more numerous these shells are in the surface waters, the greater is the depth at which they will accumulate at the bottom. As a rule, a ptero-

pod ooze or a globigerina ooze is found in deeper water in the tropics than in temperate regions.

The red clay occupies those portions of the ocean's bed in the central parts of the ocean basins where the carbonate of lime surface shells have been almost or completely removed. The composition of this clay is rather varied. Mr. Murray has shown that it is most largely composed of fragmental volcanic material, which in very many cases has undergone profound alteration. He also points out the important part played by floating pumice-stone in the formation of oceanic deposits. After volcanic eruptions, such as that of Krakatoa, the sea is frequently covered for square miles in extent with floating pumice. These fragments are carried far and wide by ocean currents, and are often arranged in long lines on the surface of the ocean; they are knocked against each other by the action of the waves, and there results from this trituration a fine rain of dust, which falls to the bottom of the sea.

The larger fragments themselves become water-logged after a time, and also fall to the bottom. These pumice-stones have been found in all the varieties of deposits, but they are especially abundant in the red clay areas. At the foot of Misti, near Arequipa, Peru, the torrent which sweeps round its base carries during floods quantities of pumice, which are drifted out to sea and float for a time along the coast. Mr. Murray has also shown that these pumice-stones are occasionally thrown up on coral islets in immense numbers, and, there decomposing, form the red clay and red earth of these islands, the source of which was long a great mystery. During the "Challenger" expedition, pumice was continually taken in the tow-nets in all parts of the ocean's surface. There is also abundant evidence, in many deposits and fragments, of showers of volcanic ashes, most probably derived from submarine eruptions. In the red clay areas these volcanic matters have usually undergone decomposition into clay, and also have given rise to other secondary products, such as manganese nodules (Fig. 185) and zeolitic crystals.

It must be remembered that all the bottom deposits merge into one another, and at times it is difficult to say whether a

deposit should be called a red clay, or a radiolarian ooze, or a globigerina ooze, or a blue mud. A pteropod ooze frequently contains many globigerinæ, a red clay many radiolarians or

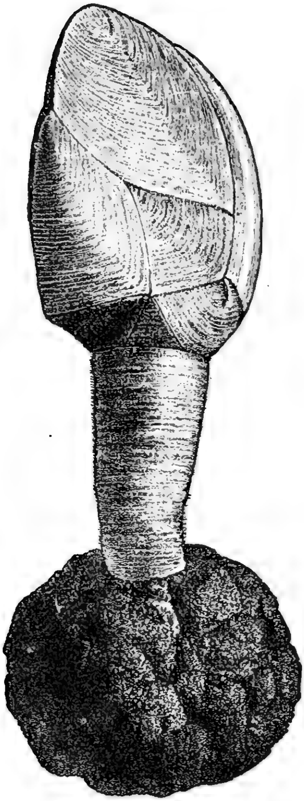


Fig. 185. — Scalpellum Darwinii, attached to manganese nodule. (Chall.) $\frac{1}{1}$.

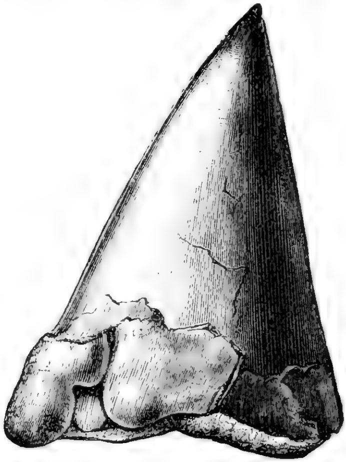


Fig. 186. — Shark's tooth (Oxyrhina), 2,350 fathoms. (Chall.)

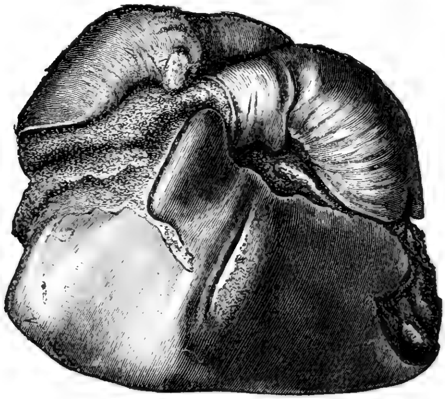


Fig. 187. — Ear-bone (Zyphius), 2,375 fathoms. (Chall.)

globigerinæ, and a blue mud may have a large proportion of those organisms so characteristic of true deep-sea deposits.

From the slow rate of accumulation of the red clay in the deep regions of the Pacific lying far from land, we may infer that the remains of tertiary sharks and whales are buried on the bottom. These are probably mingled with such bones of their recent representatives, teeth (Fig. 186), ear-bones (Fig.

187), and the like, as have not been removed in solution; only the densest bones remaining, around which have formed deposits of manganese (Fig. 188) and iron. Here the rate of deposition is at the minimum. After this come radiolarian ooze, diatom ooze, globigerina ooze, and pteropod ooze, the terrigenous deposits upon the shores of the continents accumulating at the highest rate.

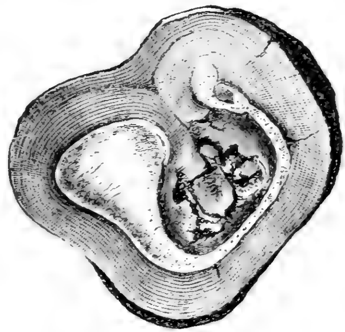


Fig. 188. — Section of manganese nodule showing tympanic bone of Mesoplodon. (Chall.) 2,600 fathoms.

Near the shore, in proximity with the hundred-fathom line, there is undoubtedly held in suspension in the water an immense amount of decaying organic matter, both animal and vegetable, in connection with the detritus swept into deeper water from the shores of the continental masses; and this probably accounts for the presence of glauconite and phosphatic nodules in these areas. At a distance from shore, the supply is limited to the dead organic matter which finds its way to the bottom, — the remains of the pelagic fauna and flora. In areas not in the track of oceanic currents, or which do not underlie regions where pelagic algæ float with more or less regularity, this supply must be infinitesimal.

We owe to Pourtalès the first general sketch of the bottom deposits around the eastern shores of the United States. He availed himself of the earlier results obtained by Professor Bailey from the examination of the deep-sea soundings submitted to him by the Coast Survey, and, supplementing these by his own observations, he published in Petermann's Journal a map of the bottom of the western Atlantic, adjoining the coast of the United States. In that memoir he calls attention to the main subdivisions of siliceous sand and calcareous deposits, the first extending along the eastern coast from New England as far south as Cape Florida, and the second around the southern extremity of Florida, the Bahamas, and a part of the coast of Cuba.

The explorations of the "Blake" have extended our knowledge of the bottom deposits of our coasts so as to include the Gulf of Mexico and the Caribbean. Within the Caribbean, the explorations of the "Blake" have been supplemented by those of the "Albatross." In addition to the soundings of the "Blake" on the eastern edge of the Gulf Stream, and in the basin of the western Atlantic between the West India Islands, Bermudas, and New York, we have a few observations made by the "Challenger." The work of the "Blake" on the southern coast of New England has been materially advanced by the continuous explorations of the United States Fish Commission during the past years.

From these different sources we may obtain a moderately complete sketch of the character of the bottom deposits of the western Atlantic, and of the adjoining enclosed seas. For the sake of convenience, we shall describe in order the deposits procured from the Gulf of Maine, and from the eastern coast as far south as Cape Hatteras; next, the specimens from the coast south of Hatteras, to latitude 31° 48′ N., off the northern extremity of the Bahamas; then those of the Gulf of Mexico, of the Caribbean, and of the West India Islands, closing with the description of the deposits of the basin of the western Atlantic. I shall transcribe descriptions from Mr. Murray's report on the deposits collected by the "Blake," adding observations of general interest from the soundings of Pourtalès and of the Fish Commission, and from my own.

"The deposits procured in the Gulf of Maine, and along the east coast of the United States as far south as Cape Hatteras, consist of blue or gray colored muds and sands.[1] The muds are darker-colored when wet, earthy, plastic, more or less granular, and coherent, drying into hard lumps. These deposits are chiefly made up of the *débris* of the land of the North American continent.

"In 1,240 fathoms and Lat. 38° 34′ N., off the coast of New England, the 'Challenger' dredged many rounded and angular pebbles of milky and hyaline quartz, fine-grained quartzites, feldspathic quartz-

[1] The sandy deposits are found only within 100 fathoms. They lie between the coast and the inner edge of the Gulf Stream. The greatest depths of the tract examined by the "Blake" along our eastern coast are 1,394 and 1,186 fathoms, which are situated between thirty and forty miles outside the 100-fathom line.

ites, mica schists, serpentine rocks, and compact limestones. These fragments were not larger than six or seven centimetres in diameter. The 'Blake,' in 1,241 fathoms, and Lat. 39° 43′ N., dredged large fragments of the same rocks, some of which were glaciated. In Lat. 41° 14′ N. and 1,340 fathoms the 'Challenger' again dredged similar rock fragments, and one block of syenite weighing five hundred-weight. These deposits being all within the influence of the Labrador current, these rocks may be regarded as chiefly ice-borne. The mineral particles[1] and clayey matter usually make up from eighty to eighty-five per cent of the whole deposit.

"The carbonate of lime in these deposits varies from about three to eighteen per cent; it consists of coccoliths and coccospheres, of pelagic and other foraminifera, and of fragments of echinoderms, polyzoa, ostracodes, and mollusks. The pelagic foraminifera shells and coccospheres are more abundant in the deeper deposits far from the land than in those from shallower water near the coast.

"The siliceous remains of diatoms, radiolarians, and sponges, together with arenaceous foraminifera and glauconitic casts of calcareous foraminifera, make up sometimes four or five per cent of the deposit. Mixed with the mud are also found pinnules of crinoids and otoliths of fishes."

Mr. Pourtalès noticed, from his examination of the large collection of foraminifera brought together in the soundings made by officers of the Coast Survey, that off our Atlantic coasts certain forms of foraminifera characterized distinct regions.

"The first, nearest the coast line, is marked by a great poverty of forms. Excepting a few small Polystomellæ, we find nothing in the sand, which is kept in continual motion by the waves. This region may be considered to extend to a depth of ten or twelve fathoms. Farther seaward there are different species of Miliolinæ, but not in large numbers. They extend to about forty fathoms, and also beyond, as it were sporadically. . . .

"From twenty-five to seventy fathoms *Truncatulina advena* D'Orb. is the characteristic form. The next region, that of the larger Marginulinæ and Cristellariæ, encroaches on the first; it begins at a depth of about thirty-five fathoms, and extends one hundred fathoms beyond. . . .

"From a depth of sixty fathoms the sand begins to be mixed with Globigerinæ, their numbers increasing so much with the depth that at

[1] The mineral particles consist of fragments of ancient rocks, quartz, monoclinic and triclinic feldspars, magnetite, hornblende, augite, mica, tourmaline, and occasionally glauconitic grains.

one hundred fathoms they equal in bulk the grains of sand, and in greater depths they become the chief constituents of the sea bottom, thus gradually passing into and leading us to the true calcareous globigerina ooze, and finally disappearing into the red clay formation, in the deeper parts of the Atlantic basin.

"In the mud of the 'Block Island soundings,' and of the 'mudholes' off New York, we find very little besides a few Guttulinæ.

"The same general distribution prevails all the way to Cape Florida, with few exceptions. Interruptions are rare in this great sandy plain of the continental shelf. We find only one or two small rocky patches in the neighborhood of the entrance to New York Bay."

A triangular area of clayey bottom, of considerable extent, within the hundred-fathom line, extends within the usual limits of the siliceous sands south of Block Island. The northern and southern extensions of this clay deposit, as it gradually fades, or is covered by globigerina ooze, can be traced many miles along the slope of the continental shelf.

Professor Bailey noticed in the soundings off Montauk Point, in fifty-one fathoms, an extraordinary development of foraminifera, rivalling in abundance, as he says, the vast accumulations of analogous forms constituting the marls under the city of Charleston, S. C. In the more southerly soundings of similar depths, a greater number of globigerinæ are found, as well as other genera known to occur in large numbers round the shores of Florida and the West India Islands. Professor Bailey also calls attention to the fact that these Mexican and Caribbean types are not represented in the chalk, but are very common in the tertiary deposits; their absence from deep-sea soundings seems to afford additional evidence of the difference in depth at which cretaceous and tertiary beds have been deposited. He further suggests that the immense development of globigerinæ and other pelagic foraminifera, forming a perfect milky way along the course of the Gulf Stream, may be due to the high temperature of its surface waters; and that the deposits under Charleston may have been produced under the similar influence of an ancient Gulf Stream. According to Bailey, the soundings around the Atlantic shores and in the course of the Gulf Stream present no analogy to the vast accumulations of infusoria which occur in the miocene marls of Virginia and Maryland.

The soundings of the Fish Commission between southern New England and the latitude of Chesapeake Bay were not carried on at a sufficient distance from the continental shelf to reach the limits of the red clay. Even in the deepest soundings, the globigerina ooze was still quite impure, being always more or less mixed with sand and clay mud. In a number of localities, the bottom between 500 and 1,200 fathoms consisted of tough and compact clay, of which large angular masses, weighing more than fifty pounds, were brought up in the trawl by the "Albatross." [1] In other localities, in 1,000 to 1,600 fathoms, the bottom appeared to be covered with flattened crust-like concretions of clay, containing iron and manganese oxides, these masses affording a foothold to many mollusks which could not exist on softer bottoms. Similar points of attachment are provided by the scattered boulders and pebbles found by the Fish Commission at many points on the inner edge of the Gulf Stream. These have probably been transported off shore by floating ice.

The explorations of the "Blake" and of the Fish Commission off the New England coast were not carried on much beyond the foot of the continental slope, where it passes into the western Atlantic basin. Only a portion of this region lies outside of the limits of the disturbing forces due to the action of waves, currents, and tides, which, as is known, extend to a distance of from two hundred to two hundred and fifty miles from shore, and perhaps to a depth of nearly three hundred fathoms.

Off the southern coast of New England, concretions of varying sizes were dredged by the Fish Commission in 640 fathoms, the largest weighing sixty pounds or more. They were composed of grains of siliceous sand cemented by calcareous matter. In some cases the casts of foraminifera could be identified, or fossil shells distinguished that were identical with recent species. Professor Verrill thinks these deposits may be of pliocene age, and that they probably form a part of the extensive

[1] According to Professor Verrill, this clay was mixed with more or less sand, showing grains of quartz, feldspar, and mica, tests of globigerinæ and other foraminifera making up but a small percentage of the material. Similar deposits were found by the "Blake" somewhat farther north; they contained, however, a larger proportion of foraminifera.

submarine tertiary formation which extends for several hundred miles along the outer banks, from Cape Cod to George's Bank and the Grand Banks off Newfoundland, constituting perhaps the solid foundations of the banks themselves.

The bottom of the Gulf Stream slope, from 70 to 300 fathoms, and a belt varying from sixty to a hundred and twenty miles, is composed in great part of siliceous sand, with grains of feldspar, hornblende, mica, glauconite, etc., fragments of sponge spicules, diatoms, and a very large percentage of calcareous organisms. Arenaceous foraminifera are often dredged in considerable quantities (from five to eighteen per cent). The percentage of argillaceous matter increases rapidly with the depth. At a depth of about 400 fathoms, it is not more than ten per cent; in 1,300 fathoms, nearly thirty-nine. The absence of argillaceous matter in the inner portion of the continental shelf (60 to 150 fathoms) is very marked.

Professor Verrill has called attention to the floating beach sand met with at a distance from shore, the fine argillaceous sediment being carried out to sea to sink in greater depths near the foot of the continental slope, or to mix with the globigerina ooze in the track of the Gulf Stream or in the deeper waters of the Atlantic.

The conditions under which the shells of mollusks and the hard parts of invertebrates may become fossil depend greatly upon the habits of many of the deep-sea denizens. Some of the deep-sea fishes, judging from the contents of their stomachs, must dig up the muddy bottoms in search of their food. Others again, like many of our shore fishes, swallow shells, which are disgorged subsequently unaffected by digestion. Starfishes destroy large numbers of mollusks, boring sponges and carnivorous gasteropods many more, and the bottom of districts where an abundant fauna exists must be covered with fragments of remains of invertebrates in all possible stages of conservation, ready to be imbedded in the muds, clays, or limestones forming on the floor of the ocean. Holothurians and sea-urchins work over the infusorial animals and smaller invertebrates living on the bottom, by throwing them out again after swallowing them for the sake of the organic matter they contain. Under the

most favorable conditions for their preservation, therefore, the fossils would give very imperfect evidence in regard to the variety of species which once constituted the fauna of any district.

I quote from Murray and Pourtalès : —

"Between Cape Hatteras and Lat. 31° 48′ N., the deposits are green muds or sands. They are with two exceptions under 1,000 fathoms, and are mostly under the waters of the Gulf Stream, or along its inner margin. The mineral particles are much the same as those in the deposits north of Cape Hatteras, but are all very much smaller, and have evidently not been transported by ice. The mineral particles, with the exception of the concretions formed at the bottom, seldom exceed 0.4 mm. in diameter, and consist of quartz, feldspars, augite, hornblende, magnetite, and a few fragments of glassy rocks. Glauconitic grains and casts are frequently very abundant, as are also grains of manganese peroxide.

"The carbonate of lime makes up usually over fifty per cent of the whole deposit, and consists chiefly of the dead shells of pelagic and other foraminifera, along with shells of pelagic mollusks, fragments of echinoderms and polyzoa, ostracodes, and coccoliths. All the tropical species of pelagic foraminifera are abundant in these deposits, while they were relatively rare in the deposits along the coast to the north of Cape Hatteras.

"The remains of siliceous organisms, as diatoms, radiolarians, sponge spicules, and glauconitic casts of foraminifera and other organisms, make up usually ten or twelve per cent of the deposit.

"The finer washings of these deposits are of a greenish color, which seems to be chiefly due to the presence of some amorphous organic substance, the nature of which has not yet been determined. A similar greenish matter was met with by the 'Challenger' in deposits from the same depths off the coasts of Africa, Australia, Japan, and China. These are the modern greensands and muds to which attention was first called by the late Professor Bailey.

"Many of these deposits might equally well be called globigerina ooze.

"Phosphate of lime and manganese concretions are present in all the deposits, and one remarkable concretion is described in detail, from Station 317, in a depth of 333 fathoms, immediately under the waters of the Gulf Stream. The ground from which the concretion was procured was hard, and it appears to have been formed in the position from which it was dredged. Its form was irregular, — the greatest diameter being about nine inches, — and of a mottled black and brown

color. The surface was irregular, and presented many ovoid, smooth projections, the largest of which were about one centimetre in diameter. The whole mass was overgrown with sponges, corals, and annelids. (Fig. 189.) Imbedded in the concretion were two shark's teeth, resembling *Lamna*, the larger being 2¼ inches in length and one inch

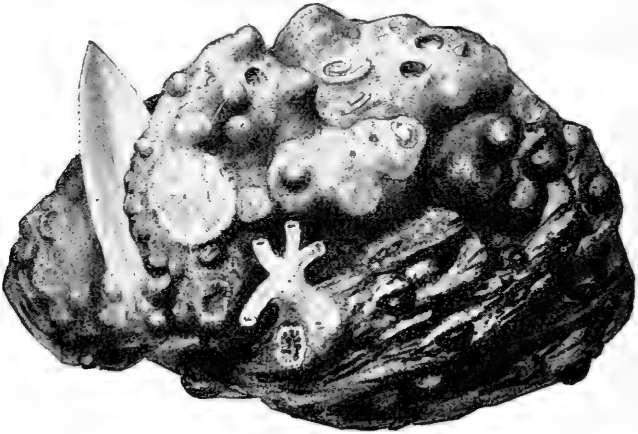


Fig. 189. — Concretion. 333 fathoms. (Blake Station 317.) $\frac{2}{3}$.

across the base. This tooth is the same as many found by the 'Challenger' in great numbers in the greater depths of the central Pacific, frequently forming the centres of manganese nodules. In the specimens from the deep water of the Pacific, the interior of the tooth had been in every instance completely removed, only the hard outer dentine remaining. In the tooth imbedded in this concretion, on the contrary, the vaso-dentine of the interior of the tooth is well preserved, in this respect resembling the shark's teeth of the same kind found in various tertiary deposits, as for instance in South Carolina and in the island of Malta. The vessels of the tooth are infiltrated with peroxide of iron and manganese, and phosphate of lime. The whole mass has a breccia-like appearance, the several fragments being cemented by deposits of carbonate of lime and manganese peroxide.[1]

[1] "When thin sections are prepared and examined with the microscope, the preparation has a variegated appearance. All the grains are closely cemented together. There are numerous sections of pelagic and other calcareous foraminifera, of pteropods, and fragments of echinoderms. The interior of the foraminifera is sometimes completely filled with calcite, and the same crystals are found cementing many of the fragments of which the rock is composed. Small fragments of quartz, of feldspar, and of zoïsite are also seen in the sections. But the most characteristic element is formed by small rounded grains of a brownish or yellow-green color, having much the aspect of glauconite, which is also present.

"There are off the coasts of North and South Carolina small rocky banks slightly raised above the general level of the sea bottom, consisting of a calcareous material, which are probably the continuation of the tertiary beds found inland along the adjoining shores. They are covered by corals (Oculina), gorgonians, and other invertebrates, and afford better feeding-grounds for fishes than the sandy bottom. They are the fishing-banks of the inhabitants. Similar banks are found off Cape Fear, and, to judge from the nature of the corals and shells thrown up on the beaches near Cape Hatteras and Cape Lookout, others probably exist in their vicinity."

In the strength of the current of the Gulf Stream the bottom was washed nearly bare, and we found little animal life in the trough of the stream. The bottom was composed of a hard limestone, the edges of the sounding-cylinder coming up much defaced. Off Charleston the whole width of the Gulf Stream was swept clean. From Jupiter Inlet to the latitude of the northern Bahamas the bottom specimens resembled more the ooze of the Gulf of Mexico and the Caribbean, containing a proportionally larger percentage of pteropod remains than the ooze farther north, where the globigerinæ increased in number.

The rapid changes in the character of the mud in proportion to the distance from shore and the depth are well shown in the nature of the deposits at different levels along the short, steep line which forms the northern slope of the Blake Plateau to the south of Cape Hatteras. There we pass quickly from the comparatively coarse shore mud to finer and finer ooze, which becomes an impalpable silt in the deeper water beyond one or two thousand fathoms, assuming at the same time a lighter color. The gradual decrease of color of the bottom deposits with an increase in depth is very evident in the soundings

Chemical reactions show that these grains are phosphatic. They are similar to the grains found in phosphatic nodules dredged off the Cape of Good Hope and elsewhere, and identical in their physical and chemical properties with the phosphatic grains in cretaceous rocks.

"The manganese is infiltrated through the whole mass of the concretion. The phosphatic grains are sometimes enclosed in the manganese. For an analysis of a portion of this concretion by M. Klement, see Bull. M. C. Z., XII. No. 2.

"The 'Challenger' dredged on several occasions, especially off the Cape of Good Hope, concretionary masses like that above described, but very much smaller. Phosphatic nodules were always found in the deposits at less than 1,500 fathoms, near continental shores, but never in the deeper deposits far removed from land."

in the Gulf of Mexico, and during my first dredging trip I was struck with the change of the light yellowish-gray ooze of the trough of the Gulf Stream into the darker shades as we approached the coast of Cuba.

While running the line parallel to the coast from off Charleston to Cape Hatteras, we came twice upon localities where the sounding-cup brought up nothing but clean globigerinæ, the bottom consisting entirely of the modern greensand[1] to which Bailey and Pourtalès had already called attention as forming off shore on the Atlantic coast of the United States. From the examination of a large number of bottom specimens, Pourtalès succeeded in determining the position of a belt off the coast of Georgia and of South Carolina where the modern greensand was well developed. The patches of greensand occurred in depths varying from fifty to a hundred fathoms on the boundary line between the siliceous sand and calcareous bottoms on the inner edge of the Gulf Stream. Now and then this modern greensand (Fig. 190) is found also in deeper water under the Stream itself. Pourtalès gives the following description of the formation of our modern greensand: —

Fig. 190. — Greensand. 142 fathoms. (Blake Station 314.) $\frac{15}{1}$.

"Ehrenberg made, as is well known, the interesting discovery that the so-called greensand or glauconite consists of the casts of foraminifera.[2] That this process is still going on at the bottom of the ocean,

[1] Murray says, that fifty per cent of carbonate of lime, mainly made up of pelagic and other foraminifera, and forty per cent of greensand residue, enter into the composition of one of the samples of modern greensand he examined. The remainder consists of siliceous organisms and argillaceous and green amorphous matter.

[2] Bailey confirmed the observations of Ehrenberg, on the greensand of the Zeuglodon limestone of Alabama, and detected the same structure in some of the cretaceous deposits of New Jersey and Texas, and in the eocene of South and North Carolina.

near our coasts, was discovered by Bailey, from the examination of our bottom specimens. In some of them the whole process can be followed in the most interesting way. Thus we find, side by side, the tests perfectly fresh, others still entire, but filled with a rusty-colored mass, which permeates the finest canals of the shells like an injection.[1] In others, again, the shell is partly broken away, and the filling is turning greenish; and finally we find the casts without trace of shell, sometimes perfectly reproducing the internal form of the chambers; sometimes, particularly in the larger ones, cracks of the surface or conglomeration with other grains obliterate all the characters. They even coalesce into pebbles, in which the casts can only be recognized after grinding and polishing.

"Why this process of transformation should occur only in particular localities is as yet unexplained.[2] It is easy to distinguish this fresh formed greensand from the tertiary one off the coast of New Jersey, by the greater number of perfect tests of foraminifera mixed with it."

As was pointed out by Pourtalès, it is remarkable how closely the limits of the siliceous sand bottom coincide with the boundaries of the cold current coming from the north, while the limits of the calcareous deposits correspond with the course of the warm waters of the Gulf Stream. We might almost trace its course by a study of the bottom specimens. On each side, as well as at the falls of the Gulf Stream south of Hatteras, ooze of varying composition was invariably brought up. The distribution of the foraminifera seems to throw considerable light on the circulation, and to give additional support to Commander Bartlett's view, based upon thermometric sections, that the bulk of the Arctic current does not extend south of Hatteras along our coast, but that the colder and heavier waters of the northern current plunge beneath the Gulf Stream off Hatteras, and flow slowly on the outside edge of the Blake Plateau towards the equator.

During the years 1875 and 1876, previous to my connection

[1] Many of the foraminifera dredged by Pourtalès and myself in the Straits of Florida were filled with a yellow mass, like that of the first stage of transformation into greensand.

[2] Bailey shows that the casts are not all due to foraminifera, but also in part to other organisms, and he suggests that we may safely infer that this matrix has invariably been formed in connection with decaying organic matter.

with the "Blake," very extensive series of bottom deposits were obtained by the vessels of the Coast Survey, at all depths and in all parts of the Gulf of Mexico. Of these deposits Murray says in his Report: —

"There is a very great variety in the shallow-water deposits under one hundred fathoms. Near the coasts of the continent along the shores of the Gulf, where rivers enter and where there are few coral reefs, the deposits are either sands or fine clayey muds, formed of detrital matter brought down from the land. We find in these muds, however, in the track of currents, a number of pelagic foraminifera as well as other calcareous organisms. Where the shores are lined by coral reefs, the deposits are chiefly made up of coral *débris*, the shells of pelagic foraminifera and mollusks, and other calcareous organisms.

"The character of the deposits in depths greater than one hundred fathoms is likewise largely determined by the greater or less proximity to coral reefs or the embouchure of rivers.

"In all the deeper deposits in the Gulf of Mexico and the Straits of Florida, the crystalline mineral particles are very small, rarely exceeding one tenth of a millimeter in diameter. They consist principally of small rounded grains of quartz, with fragments of feldspar, mica, hornblende, augite, magnetite, and rarely tourmaline. In a few places there were fragments of pumice, and glauconitic particles were occasionally noticed. The mineral particles and fine clayey matter appear to be almost wholly derived from the rivers emptying into the Gulf of Mexico.

"The carbonate of lime in the deposits of these regions is mostly made up of the shells of pelagic foraminifera and mollusks, though we also find coccoliths, rhabdoliths, and fragments of echinoderms. In depths greater than 2,000 fathoms, the pteropod and heteropod shells appear to be nearly, if not quite, absent, — the carbonate of lime then consisting of the shells of pelagic foraminifera; in lesser depths the pteropod and heteropod shells are present; and in depths of 200 to 500 fathoms they make up the bulk of the deposits in many places. In several of the deposits, where the percentage of lime is very high, the whole has a very chalk-like appearance; it appears, indeed, as if it were in the process of transformation to true chalk."

According to Murray, in the deposits of the Gulf of Mexico the carbonate of lime varies greatly. In muds brought down by rivers, there is sometimes little more than two per cent of lime. The percentage rises to ten or fifteen per cent in some of the volcanic muds. In the coral muds it varies from sixty-seven to

over eighty per cent. The variation in the percentage of lime in pteropod ooze is from sixty-eight to eighty-three. In the coral muds and pteropod and globigerina ooze, the lime is replaced in part, in accordance with the locality, by a greater or smaller amount of siliceous organisms or by argillaceous matter. The variations of lime in globigerina ooze range from thirty-two to seventy-two per cent, in proportion to the proximity of the shore, the percentage of mineral residue varying from sixty-four to twenty-seven, in addition to the changes due to a larger or smaller proportion of siliceous organisms or argillaceous matter.

While sounding, it was easy to follow the depth and the distance from shore by the gradual decrease of bright tints in the bottom specimens; these were probably colored more intensely by organic matter when close in shore, but became bleached with increasing depth. Along the lines of soundings in the Caribbean, we found the coral muds to be of a light greenish-gray or yellowish tint. Pteropod ooze varied from a chalky gray to white, while globigerina ooze passed from dark brown to reddish, reddish brown, and light brown, or cream-color. The river muds were usually gray or brown.

The globigerina and pteropod ooze of the central parts of the basins of the Gulf of Mexico and the Caribbean, like those found in proximity to the Greater and Lesser Antilles, differ materially from similar deposits in the great oceanic basins. The siliceous organisms consist of radiolarians and sponge spicules, with a few diatoms; but these seldom make up more than three or four per cent of the whole deposit. An unusual number of otoliths of fishes were detected in the bottom specimens of the Gulf of Mexico; they occurred at considerable depths, from 392 to 1,568 fathoms. Fish teeth were also found in some of the mud deposits, from over 500 fathoms.

I take the following from Murray's Report: —

"The phosphatic concretions in the dredgings in the Straits of Florida are very interesting. In a great many deep-sea deposits there is usually a small percentage of phosphate of lime, but near the shore, in some instances, the quantity is very considerable. Sharples, who analyzed the ooze of the Gulf Stream, found over eighty-five per cent of carbonate of lime, and only 0.18 per cent of phosphate of lime.

"In certain concretions found by the 'Blake' in the Florida Straits, and by the 'Challenger' in various parts of the world, near land, the quantity of phosphate of lime is very much greater. These concretions appear always to be associated in an intimate way with organisms.

"In 125 fathoms, southwest of Sand Key, a fragment of manatee bone was obtained several centimetres in diameter. It was of a dirty brown color, of great hardness, and had a conchoidal fracture. A microscopic examination of thin sections showed that the bone structure was perfectly preserved. It was found to contain over thirty-three per cent of phosphoric acid, and nearly fifty-two per cent of lime.

"From the same place was obtained a concretion of a brown color, consisting of an aggregation of calcareous organisms cemented by a brownish yellow matter, often showing concentric rings after the manner of agate.[1]

"At other stations small phosphatic concretions were also obtained by the 'Blake,' all more or less resembling those described above. There are difficulties in understanding how phosphate of lime and carbonate of lime are deposited at the bottom of the sea, yet there is no doubt that such a deposition does take place under some special circumstances. Their solution is, however, an almost universal phenomenon in the ocean."

When dredging off Cuba, Pourtalès procured, at the depth of 270 fathoms, a number of nodules of a very porous limestone, similar in color and texture to the limestone which forms the range of low hills on the shore of Cuba, and is composed of the remains of the same animals which are found living.

The globigerina ooze of the Gulf extends northward until it strikes the Mississippi River slope. Here the fauna changes, and with the presence of dark rich muds that of the deep Gulf ooze disappears, and is replaced by a number of interesting forms of annelids, mollusks, ophiurans, and sea-urchins, characteristic of the continental Gulf slope, and typical of mud deposits. Nowhere around the shores of the United States can we so readily trace the denudation of the continent as in the succession of formations which since the time of the

[1] "This yellowish brown matter is isotropic; between crossed nicols only the calcite and the shells of the foraminifera brighten up; the calcite lies crystallized in the interior of the foraminifera. In attacking the brown or yellow parts under the microscope with molybdate of ammonium and nitric acid, there is an abundant yellow precipitate characteristic of phosphoric acid."

jurassic period have gradually filled the shallow sea formerly existing to the west of the Mississippi basin and of the southern portion of the Gulf States. In more recent times, the muds brought down by the Mississippi and other rivers emptying into the Gulf of Mexico have been deposited upon its shores, and have formed the steep continental slope of the Gulf beyond the hundred-fathom line.

The recent river muds now occupy a narrow strip of the Mississippi basin, between Louisiana and Mississippi, as far north as the mouth of the Ohio. They have also built out the delta of the river to within a short distance of the hundred-fathom line, and extend along the shore of Texas, slowly filling up the Gulf of Mexico.

I was very much struck, on first seeing the ooze of the deep water of the Straits of Florida between Havana and Florida Keys, with the immense number of dead pteropod and heteropod shells which it contained, in addition to the countless tests of globigerinæ and orbulinæ. These shells belonged mainly to the genera Clio, Hyalea, Triptera, Atlanta, Styliola, etc., all of which swarm on the surface, or a little below it, in all the parts of the Gulf of Mexico which we had thus far passed over. I could at once see how important a part these dead pteropod shells must play in the formation of the sedimentary matter accumulating at the bottom. Globigerinæ and orbulinæ form, as we know, the bulk of the ooze, but the remaining part of the mud is made up mainly of the dead shells of pteropods in all stages of disintegration, from perfect shells, still filled with the decaying animals, to the most minute grains, in which we can just detect the presence of the pteropod test. This composition of the ooze is the rule in all specimens of the bottom which I have thus far had time to examine. The decay and solution of the test become more rapid with increasing depth, and may be due, as suggested by Mr. Murray, to the excess of carbonic acid present at great depths, or, as Professor Dittmar is inclined to believe, to the solvent action of the sea-water itself. In a volcanic region like that of the West Indies, there is no difficulty in accounting for the presence of a large supply of gas. To show how far the dead pteropod shells make up the globigerina

ooze, I took from the contents of the trawl drawn from 860 fathoms equal portions of mud as it came up; one part was left undisturbed and roughly measured, and the other was carefully sifted; the pteropod shells and their fragments were then collected, and likewise measured, when their bulk was found to be somewhat more than half the bulk of the sifted mud from which they came.

Pourtalès, who first traced the extent of the region covered by globigerina ooze in some parts of the Gulf of Mexico and upon the Atlantic coast of the United States, thus speaks of the foraminiferous calcareous bottom: —

"In great depths, as, for instance, in the Straits of Florida, at the outward limit of the rocky bottom (Pourtalès Plateau), and, where this does not exist, even in less depths, the bottom is covered by a chalk-like layer, which resolves itself under the microscope into a mass of foraminifera,[1] and their fragments more or less comminuted. This formation extends almost uninterruptedly in the whole bed of the Gulf Stream, in the greater depths of the Gulf of Mexico, in the deep channels which intersect the Bahama Banks, and then up the Atlantic coast from about the hundred-fathom curve outward, or from the inner limit of the Gulf Stream, which nearly coincides with it, and so over the greater part of the Atlantic basin. The discovery of this formation belongs to the year 1853, when it was found almost simultaneously by Lieutenants Craven and Maffit, then in the Coast Survey, and exploring the Gulf Stream. It became more extensively known somewhat later, by the soundings made for the Atlantic telegraph.

"The genus of foraminifera most abundantly represented in this bottom is the Globigerina; hence the term 'globigerina bottom' (ooze) is becoming generally used. Then comes in order of frequency *Rotalina cultrata;* then several Textulariæ, Marginulinæ, etc. It is now pretty generally admitted that these rhizopods live and die in these great depths,[2] although formerly false ideas of the effects of pressure, of the

[1] The extent to which pteropod shells enter into the composition of the ooze of the Caribbean and Gulf of Mexico had not then been noticed.

[2] As far back as 1850, Pourtalès stated that at depths of 257 fathoms globigerinæ are still living in immense numbers. As I have mentioned before, I found an allied species of globigerina swarming on the surface to the westward of the Tortugas. While examining the specimens of foraminifera collected by Coast Survey expeditions, Pourtalès made the interesting discovery that many specimens of Orbulina contained a young Globigerina, more or less developed, and that these two genera must be considered as probably two stages of alternate generation.

want of light, etc., seemed to militate against this supposition. But that animals living near the surface contribute also a not inconsiderable proportion, is proved by the numerous shells of pteropods, occasional teeth of fishes," etc.

It was on this bottom that Pourtalès dredged the interesting little stalked crinoid Rhizocrinus, which he referred at first to Bourgueticrinus. The importance attached to the subsequent discovery of the identity of Bourgueticrinus with the Rhizocrinus dredged by Sars off the coast of Norway, as well as by Pourtalès, Agassiz, Thomson, and Carpenter, undoubtedly awakened the general interest of naturalists to the problems of thalassography, and to the two successful hauls of the dredge in the Straits of Florida and off the Lofoten Islands we owe in great part our recent deep-sea explorations. As stated by Pourtalès, —

"The sandy bottom ends exactly at Cape Florida. Key Biscayne, of which the southern point is Cape Florida, consists in great part of siliceous sand. The next island to the southward, only five miles distant, shows no trace of sand, but consists exclusively of coral limestone, of which the whole range of the Florida Keys is also formed.

"About Cape Sable siliceous sand reappears, and extends along the western coast of Florida, though at first strongly mixed with lime.

"It is remarkable how the littoral fauna changes with the constitution of the bottom. Many forms of animals peculiar to the Carolinian fauna disappear at Cape Florida, and reappear at Cape Sable and on the west coast of the peninsula. Between these points they are entirely crowded out by the interposition of the West Indian fauna of the coral reefs. To take but one example, oysters are not found on the coral bottom, though abundant to the east and west on the sandy bottom."

This shows that the nature of the bottom far more than the depth is the cause of the abrupt changes of fauna which are observed when we pass from one kind of bottom to another.

To the westward of the shores of the southern extremity of Florida we gradually come upon the belt of mud, more or less mixed with calcareous matter, which stretches from Florida towards deep water and around the shores of the Gulf of Mexico, until it strikes again the calcareous deposits of the Yucatan

Bank. The structure of the limestone banks which form the greater part of the peninsula of Florida, of Yucatan, of Honduras, of the Bahamas, and of the extensive ancient and modern coral reefs of Cuba and the greater and lesser Antilles, and extend along the northern coast of South America, has been already described in the chapter on the Florida Reefs. I merely allude to their general position to point out the connection of these immense deposits of limestone with the calcareous bottom of the deeper parts of the floor of the Caribbean and of the Gulf of Mexico.

The distribution of the recent coral reefs is shown on the map. (Fig. 191.) The coral bottom, or coralline sand, which owes its origin to their presence, extends but a short distance in depth; the coral reefs proper being sharply limited in depth, as reef-building corals only flourish within very moderate depths. On the surface, the slope is made up of fragments of shells, of the tests of invertebrates, and of similar material more or less broken and worn, which reaches to a depth of about a hundred fathoms or more. But nowhere in the West Indian area do we meet with the steep slopes which have been described as characteristic of the coral islands of the Pacific.

Outside of the reefs we pass into a layer of soft, calcareous ooze, whiter nearer the reefs, and becoming somewhat colored at a greater distance. The whole deposit "is an immense layer of chalk, to which the organic life developed on its surface is constantly adding; while nearer shore the faunæ of the littoral and deep-sea regions, with their numerous corals and shells, contribute to the formation of limestone of various characters, such as oölite, muschelkalk, coral rag, and conglomerates from beds broken up and reconstructed."

The explorations of Pourtalès along the Florida reefs developed an extensive limestone plateau, to which the name of Pourtalès Plateau has been given. This rocky plateau, with a very moderate slope, begins a little to the westward of Sand Key, and stretches to the northward and eastward, until it reaches its maximum breadth, of about eighteen nautical miles, to the eastward of Sombrero. It then diminishes in breadth, and finally ends between Carysfort Reef and Cape Florida, at the same

time approaching the reef. The plateau begins at a depth of about 90 fathoms, and ends at about 300.

The bottom, as described by Pourtalès, is rocky, rather rough, and consists of a recent limestone (Fig. 192), continually though slowly increasing from the accumulation of the calcareous *débris* of the numerous small corals, echinoderms, and mollusks living on its surface. These *débris* are consolidated by tubes of serpulæ; the interstices are filled up by foraminifera, and further smoothed over by nullipores. The region of this recent limestone[1] ceases at a depth varying from 250 to 350 fathoms, and beyond it comes the trough of the straits. The bottom here forms a great bed of foraminifera, and especially of globigerinæ, which so extensively covers oceanic basins.

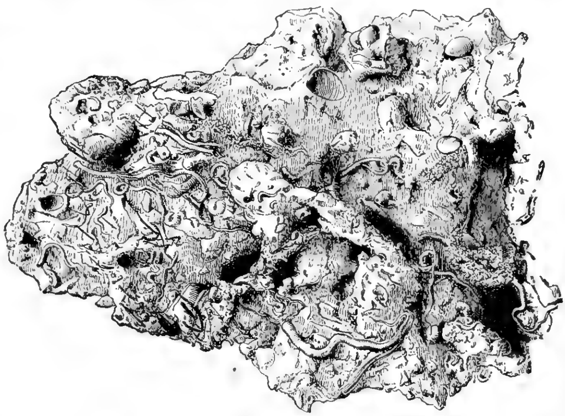


Fig. 192. — Rock from Pourtalès Plateau.

If uncovered, the Pourtalès Plateau would be found to be built up of beds of limestone filled with fossils, the remains of the animals now living on its bottom, with such pelagic forms as have sunk after death, like the remains of fishes and of pelagic mollusks, or which, like the bones of manatee, may have been brought by currents from the littoral regions. The rich fauna of the reef extends but slightly seaward, and until we reach about the hundred-fathom line the coast shelf is singularly barren; but beyond this, we find a region remarkably rich in animal forms. The fauna found on the Pourtalès Plateau is undoubtedly due to the action of the Gulf Stream, which supplies the animals living upon it with an abundance of food, and,

[1] It would be an interesting experiment to determine the specific gravity of rocks taken from deep water, and to compare, for instance, recent dolomite and recent limestones with the specific gravity of similar rocks.

in addition, sweeps the floor of the plateau clear of all fine sedimentary accumulations.[1]

"A similar sea-bottom, but with a very steep slope, is formed on the north side of Cuba, to a depth of three or four hundred fathoms, also inhabited by a rich fauna, which presents, however, considerable differences from the one just mentioned, notwithstanding the short distance between the two coasts." (Pourtalès.)

Near the Bahama Banks, Pourtalès found the steep slope covered with calcareous sand. In his description of the fauna of these plateaux he called attention to the resemblance of many of the types described by him to tertiary and cretaceous forms, and to their extended geographical distribution.

Mr. Murray thus describes the typical bottom deposits of the Caribbean district: —

"The specimens procured around the shores of the Greater and Lesser Antilles are chiefly from depths between a hundred and one thousand fathoms, although a few are in depths less than a hundred fathoms and a few are over two thousand fathoms. They are all in more or less close proximity to the coasts. The mineral particles are chiefly

[1] The hard parts of the corals, mollusks, sponges, and other invertebrates, which build up the limestone of the Pourtalès Plateau, are often riddled with canals made by vegetable parasites, or by boring sponges. The former often form beautiful networks. Their manner of boring is not well understood. Wedl and Kölliker suggest that the vegetable parasites may dissolve the carbonate of lime by emitting an acid as they advance, at their terminal extremity. In the case of boring sponges, the penetration is probably mechanical. The canals, like the surface of many of the concretions from these regions, are frequently coated with a glaze of manganese.

Sharples found traces of oxide of iron in the ooze he analyzed from the Straits of Florida, and a considerable quantity in the concretions and specimens of rock of the Pourtalès Plateau. The presence of iron in a closed sea, like the Gulf of Mexico, is readily accounted for by the presence of large rivers carrying down into it large quantities of iron. The waters from the open ocean are nearly free from it. The following are Sharples's analyses: —

	Rock Concretion.	Rock and Corals.	Limestone.	Ooze.
Carbonate of lime	36.50	47.11	96.96	85.62
Tricalcic phosphate	35.54	13.15	1.20	.18
Silica	.49	1.92	2.12	1.52
Ferric oxide	14.77	20.23	—	.31
Carbonate of magnesia	10.56	12.39	—	4.26
Organic matter and water	1.46	5.89	—	8.15
	99.32	100.69	100.28	100.04

fragments of volcanic rocks, or crystals derived from these.[1] In the deposits farthest from land the size of the mineral particles seldom exceeded 0.1 mm. in diameter, but near shore they were very much larger, and fragments of rocks and pebbles were frequently dredged.

"The percentage of carbonate of lime in these deposits was usually very high, being frequently seventy or eighty per cent, and in the case of a chalk rock 90.24 per cent. This lime consisted of fragments of shells of pelagic and other mollusks, of calcareous algæ, of echinoderms, of annelid tubes, of corals, polyzoa, alcyonarian spicules, coccoliths and rhabdoliths, and of pelagic and other foraminifera. Where the shores were composed of volcanic or other rocks not calcareous, the *débris* of these made up the larger part of the deposits, which might be called volcanic muds. But the majority of the deposits should be termed pteropod or globigerina ooze, owing to the large number of these organisms present in them. The ooze varies greatly in color. The pteropod ooze is either a white, a yellowish brown, or a dark brown; the globigerina ooze ranges from a light gray to light brown, the coral muds are yellowish and white, and the volcanic muds light brown. The darker-colored ooze and mud usually occur nearer shore than the lighter ooze found in the central parts of the basin of the Gulf of Mexico and in the Caribbean. It should be remembered, however, that, both in the size of the mineral particles and the nature of a large number of the calcareous particles, these deposits differ considerably from similar deposits found far away from land in the open ocean, and called also pteropod and globigerina ooze.

"The siliceous organisms never make up more than four or five per cent of the whole deposit, and consist of radiolaria, sponge spicules, and a few diatoms.

"From 994 fathoms, off Nuevitas, Cuba, there was obtained a fragment of white chalk coated on the surface with streaks of peroxide of manganese. This chalk contained 90.24 per cent of carbonate of lime. The sections showed the rock to be composed of crystalline grains of carbonate of lime, but not the result of precipitation. A few sections of globigerina and textularia were observed, but no other organisms could be recognized. After dissolving away a considerable quantity, small fragments of quartz and hornblende, sponge spicules, and radiolarians were recognized in the residue. It is not possible to be certain that this rock was formed in the position from which it was dredged,

[1] Monoclinic and triclinic feldspars, hornblende, augite, olivine, magnetic iron, and pumice; fragments from ancient rocks, as quartz, tourmaline, mica, epidote. Glauconitic grains were rare in these deposits, and phosphatic grains were likewise rare. Altered fragments of plagioclase, basalts, and diabase were rather frequent.

though there are reasons for supposing it was. The ooze which came up from the same place was of a reddish or brownish tinge, and contained an immense number of pteropods, heteropods, and pelagic foraminifera; the percentage of lime was not so high as in the white chalk rock, and the residue was much darker in color.

"Calcareous concretions and nodules of manganese were also dredged in this district." [1]

In the district around the shores of the Antilles there is a gradual transition from the coarser volcanic bottom deposits of shallow waters to the finer sands and muds, which at a distance from the islands pass into ooze. While dredging in the passages between the islands the trawl often came up well filled with rounded pebbles of volcanic rocks. Their shape may be due either to the action of the strong currents rushing between the islands, or perhaps to the disintegrating action of the warm water. This process may account for the abundance of the coarse volcanic sands found in the West Indian waters. Below six or seven hundred fathoms the bottom in the Caribbean is composed of calcareous ooze, consisting in great part of pteropod shells, and in a less degree of foraminiferous remains.

[1] "Off the Barbados, in 221 fathoms, a very hard calcareous concretion was obtained, which showed perfectly how the rock was formed by crystallization of carbonate of lime around the shells of foraminifera and other centres. A zone is seen around the shells, composed of fibro-radiate calcite; the crystals of calcite, coming from the various centres, abut against each other, and frequently leave an empty space between them. When these spaces are filled by a further deposition of lime, the whole becomes very compact and massive.

"The centres of the foraminifera are frequently filled with a gray or yellowish substance, which does not, however, give the reactions of phosphate of lime.

"The mineral particles were very few in number, among them fragments of quartz and plagioclase being observed. This concretion was about two inches in diameter, and had a rough areolar surface on which serpulæ and polyzoa were growing.

"A similar and somewhat larger concretion from 200 fathoms (Station 291) was also obtained off Barbados, which was much more overgrown with organisms, and on its upper surface had a large cavity in which a hermit-crab, *Polycheles Agassizii*, had lived. (See Bulletin M. C. Z., VIII. No. 1.)

"Off the north coast of San Domingo, in 772 fathoms (Station No. VI), were obtained several small manganese nodules and a few fragments of a Corallium coated with manganese, precisely similar to that dredged by the 'Challenger' in 1,525 fathoms near Cape Verde. (See Narrative of the Challenger, p. 125.) The nodules were of a light brownish color inside, composed in all cases of a mass of pelagic foraminifera. The largest of these nodules had a diameter of about two inches."

While dredging to the leeward of the Caribbean Islands, we could not fail to notice the large accumulations of vegetable matter and of land *débris* brought up from deep water many miles from the shore. It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and of sugar-cane, dead land shells, and other land *débris*, undoubtedly blown out to sea by the prevailing tradewinds. We frequently found floating on the surface masses of vegetation, more or less water-logged, and ready to sink. The contents of some of our trawls would certainly have puzzled a palæontologist; between the deep-water forms of crustacea, annelids, fishes, echinoderms, sponges, etc., and the mango and orange leaves mingled with branches of bamboo, nutmegs, and land shells, both animal and vegetable forms being in great profusion, he would have found it difficult to decide whether he had to deal with a marine or a land fauna. Such a haul from some fossil deposit would naturally be explained as representing a shallow estuary surrounded by forests, and yet the depth might have been fifteen hundred fathoms. This large amount of vegetable matter, thus carried out to sea, seems to have a material effect in increasing, in certain localities, the number of marine forms.

We can thus see the method by which land shells, small saurians, and insects of all sorts, may readily be transported from island to island, and we might possibly trace the actual path taken by the immigrants into the Lesser and Greater Antilles from the northern parts of South America.

We made three casts off the coast of Cuba, between Nuevitas and Cape Maysi. In Lat. 21° 2′ N., Long. 74° 44′ W., off Cayo de Moa, in 1,554 fathoms, we found a patch of greensand, made up of large globigerinæ, similar to that mentioned by Pourtalès in his "Deep-Sea Corals." We also obtained, in 994 fathoms off Nuevitas, large blocks of genuine white chalk, composed mainly of globigerinæ and pulvinulinæ. Large quantities of ooze and white clay, which proved to be only the white chalk in different stages of compression, also came up in the trawl. If the conditions now existing at that depth at all resemble those of the time of the white chalk, I can readily un-

derstand how perfectly sea-urchins or mollusks would be preserved in this homogeneous substance, and gradually compressed into solid white chalk.

Commander Bartlett observed that the strong current passing over the ridge of the Windward Passage between Cuba and San Domingo swept it entirely clean, so that but little animal life was found to live upon it. But immediately beyond this, on the Caribbean side, the mud and silt are deposited in great quantities, and animal life becomes plentiful again. This, as I have already stated, was also our experience while dredging along the so-called axis of the Gulf Stream. The bottom of that region, swept clean by the Stream, forms a great contrast to the slope off Hatteras, where the silt accumulates in such masses as to make it often difficult to detach the shot of the sounding-wire when it has sunk deep into it. These and similar deposits, accumulating within restricted areas, may often guide us in determining the direction of currents, and the distribution of pelagic types may also assist us in defining the slower movements of large masses of water.

The red clay deposit first discovered by the "Challenger" is found at depths greater than two thousand fathoms, and is probably in part the result of the decomposition of volcanic products. The materials of the red clay are present in all deposits, but at lesser depths its presence is obscured by the more rapid accumulation of calcareous matter. Near shore, and upon our continental shelf or near its base, even at very considerable depths,[1] we do not find the characteristic red clay deposit of the deeper basins of the Atlantic. Its presence is hidden by the larger mass of continental detritus, of volcanic muds and sands, of globigerina ooze, and of other calcareous deep-water deposits.

According to the "Challenger," red clay has not been found in the western basin of the North Atlantic except at one locality a little to the westward of the Bermudas. There seems to be a triangular-shaped basin filled with red clay to the eastward of

[1] This has been the experience of both the "Blake" and of the U. S. Fish Commission, when dredging at depths from which genuine red clay was brought up by the "Challenger" in more favored localities.

the Bermudas, and extending to the north as far as latitude 38°. Commencing at about longitude 50° W., it follows southward and westward toward South America nearly the line between two and three thousand fathoms. It has been found close to Porto Rico in deep water, and covers the floor of the ocean between it and the Bermudas. The western boundary of the red-clay basin is not yet clearly defined. A narrow strip of this basin reaches southward towards the ridge which separates it from the northern extremity of the red-clay basin of the western South Atlantic. The smaller red-clay basin of the eastern Atlantic lies between the Cape Verde Islands and the Dolphin Rise. The eastern red-clay basin of the South Atlantic, separated by the Challenger Ridge from the western red-clay basin, is situated to the westward of equatorial Africa. The western red-clay basin of the South Atlantic probably stretches into the Southern Ocean.

XIII.

THE PHYSIOLOGY OF DEEP-SEA LIFE.

I HAVE no observations of my own to present in regard to the composition of sea-water. For convenient reference, the interesting results of the chemists of the "Vöringen" and "Challenger" are here given in a condensed form.

As early as 1872, the chemist of the German expedition to the North Sea and the Baltic, Dr. Jacobsen, successfully extracted at sea the gaseous elements of sea-water. The apparatus which he used was subsequently adopted by other expeditions, with but little modification.

On board the Norwegian vessel, the "Vöringen," Dr. Tornöe employed a machine modified by Captain C. Wille, consisting of a spiral tube nearly five feet in length, open at both ends, through which water passes freely as the instrument is lowered. When raised the ends are closed by conical valves worked by screw fans, which, as in the case of the Sigsbee cup, revolve in one direction while going down, and in the opposite while ascending, the valves closing in a short distance.

The difficulty of making an analysis of gases on board a small vessel is very great, though the separation of the gases from the sea-water is not a hard process, and is accomplished by an apparatus not materially different from that employed by Bunsen. But the modification made in this apparatus by Dr. Behrens (Fig. 193) is all-important, and renders the operation comparatively easy. The attempt made on the "Blake" with Bunsen's apparatus failed, partly from want of room, and partly from my want of familiarity with the work.

The apparatus is made up of a flask for the reception of the sea-water to be tested, and of a bulb-tube connecting with the

mouth of the flask by a close-fitting india-rubber stopper. The tube of the bulb has a lateral opening from an ingenious slide-valve between the bulb and the flask. To the upper part of the bulb is attached a gas-tube with a double-ended pipette, in which a vacuum is formed by boiling out distilled water from the bulb, closing the upper end of the gas-tube, and then making a connection with the flask, which under the relieved pressure will allow the gas contained in the sea-water to find its way into the gas-tube. This is then sealed at the other extremity, and the contents analyzed on shore.

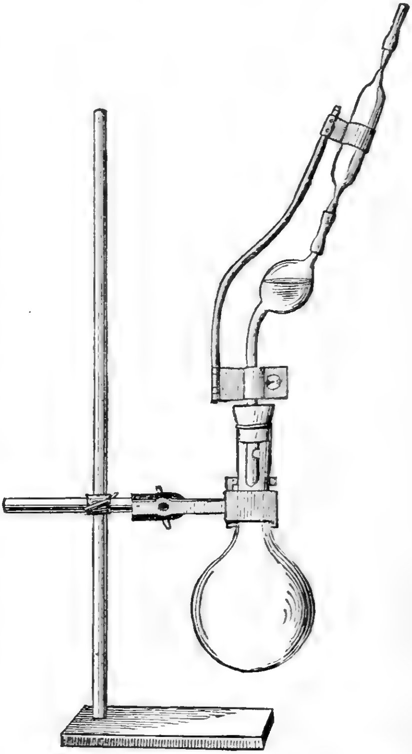


Fig. 193. — Bunsen's apparatus, modified by Jacobsen and Behrens.

Dr. Jacobsen concluded from his analyses that the percentage of oxygen in sea-water was practically invariable, the lowest and highest percentages being 33.64 and 34.14. While this is undoubtedly true for limited areas, the analyses by Dr. J. Y. Buchanan of the "Challenger" show that, under varied conditions of temperature, there was a somewhat wider range, — between 33 and 35 per cent, in round numbers. The proportion of oxygen being greatest on the surface, it begins at once to diminish rapidly till it reaches more slowly a minimum, at a depth of 300 fathoms; and below this depth, its percentage remains constant. This does not quite agree with Dittmar's results stated further on.

The carbonic acid in the water was determined directly by distilling in a current of air conveying the gas, and collecting the steam and carbonic acid in a vessel charged with baryta water. By adding to the water to be tested a measured quantity of acid

of known strength, and driving off the liberated carbonic acid by boiling gently and collecting it in baryta water of known strength, the amount of acid neutralized will give the carbonic acid present as neutral carbonate; the quantity of baryta neutralized will give the total amount of carbonic acid.

More than thirty elements are known in solution in ocean-water, but in such minute quantities that no attempt can be made to determine them from small samples. Forchhammer's memoir dealt with surface water only; but he stated that the percentage of the salts of the sea-water was the same in all parts of the ocean. Dittmar extended this, and proved that in depth also the composition was subject to but one exception: the proportion of lime was larger in very deep water than near the surface.

Professor Dittmar, in his admirable Report on the samples of sea-water collected by Dr. Buchanan, the chemist of the "Challenger," gives the following analyses as the average composition of ocean-water salts: —

"Chlorine	52.292
Bromine	0.1884
Sulphuric acid	6.410
Carbonic acid	0.152
Lime [1]	1.676
Magnesia	6.209
Potash	1.332
Soda	41.234
(Basic oxygen, equivalent to halogens)	(—12.493)
Total Salts	100.000

"Giving the following as the average composition of sea-water: —

Chloride of sodium	77.758
Chloride of magnesium	10.878
Sulphate of magnesium	4.737
Sulphate of lime	3.600
Sulphate of potash	2.465
Bromide of magnesium	0.217
Carbonate of lime	0.345
Total Salts	100.000"

[1] The amount of lime is as 10,000 : 247 in the West India seas, and as 10,000 : 371 in the Baltic.

The quantity of carbonic acid in the water is not yet definitely settled. Water kept for several years is of no use for analyses. Dittmar found that free carbonic acid in sea-water is the exception: as a rule, carbonic acid is less than the proportion corresponding to bicarbonate. In surface water the carbonic acid increases when the temperature falls, and *vice versa*. Within equal ranges of temperature, it seems to be lower in the Pacific than in the Atlantic. The alkalinity of bottom waters was found to be distinctly greater than that of surface water. There is in sea-water salts a distinct preponderance of free over fixed acid, the difference being probably due to carbonates. Dittmar says that sea-water, even when alkaline, takes up additional carbonate of lime, if sufficient time is given.

The only source of oxygen and nitrogen present in sea-water is in the atmosphere, their quantity being dependent on surface conditions, and not on the depth. Thus, owing to the constant oxidation which goes on, sea-water must continually be losing its oxygen in proportion to the depth. Dittmar found that there was nothing characteristic of bottom waters, as such, in regard to their absorbed gases, — nothing to distinguish them from waters of intermediate depths. With reference to the absorption of oxygen and of nitrogen by sea-water, the amount of air which ought theoretically to be absorbed by sea-water of the temperature and at the pressure at which samples were collected was calculated; from the quantity of nitrogen found, the amount of oxygen which should be associated with it was reached.

The quantity of air found is usually less than what is theoretically called for, — probably from the fact that the water in the ocean is always in motion, the temperature and pressure varying greatly with the locality. Air is not taken up in deep water; it is absorbed elsewhere at the surface, and its presence at any point is due to the constant movement of the waters.

There is no definite relation in the ratio of carbonic acid to oxygen present over any area. It seems to depend not so much on the depth as on the abundance and character of the fauna found at certain depths. From the action of the waves, oxygen finds its way down from the surface, and is resorbed subse-

quently; while the carbonic acid, coming from the shores and from the disintegration of the rocks, is held in solution. Were it not for the constant movement of the sea, the stagnation of life would soon become universal.

The specific gravity of ocean waters, free from the effects of local disturbing influences due to proximity of land, is found to vary within very narrow limits, — between 1.024 and 1.028,[1] reduced to a standard temperature of 60° Fahrenheit, or 15.56° Centigrade. Mr. Buchanan found that the concentration of the waters of the Atlantic was greater than that of either the Pacific or the Southern Ocean, and greater in the North Atlantic than in the South Atlantic. Below the surface the specific gravity decreases gradually until a minimum is reached at about eight hundred or one thousand fathoms,[2] and then increases slightly towards the bottom, where in the South Atlantic and Pacific quite a uniform specific gravity prevails.[3] In the equatorial regions the specific gravity first increases to a depth of from fifty to one hundred fathoms, and then follows the same course as in other parts of the ocean.

In the North Atlantic, the bottom specific gravity is comparatively high. The principal causes for this concentration are apparently the tradewinds, which, as has been suggested, increase in their capacity for taking up moisture as they proceed on their course from colder to warmer latitudes of the trade regions in the Atlantic; in higher temperate latitudes the opposite effect is produced by prevailing westerly winds, which soon become saturated with moisture in the warmer latitudes from which they rise. A similar concentration is also brought about by the formation of ice. The accumulation of salt in the northern Atlantic is naturally removed by the slow flow from north to south which probably takes place in the North Atlantic below the depth of about one thousand fathoms. Similar conditions undoubtedly exist in the Pacific, but it is more difficult to trace them.

[1] The differences in specific gravity due to differences of temperature are far greater than those arising from the percentage of salt.

[2] Buchanan's observations show that sea-water is approximately compressed in the ratio of 0.0009 for every hundred fathoms of depth.

[3] Of 1.0257 to 1.0259.

The specific gravity of the surface water of the American coast, as worked up by Mr. Buchanan from the observations of the "Challenger" and other vessels, is as follows: —

In the Atlantic outside of the West India Islands (Fig. 194), close to the American coast, on a line about at the end of the

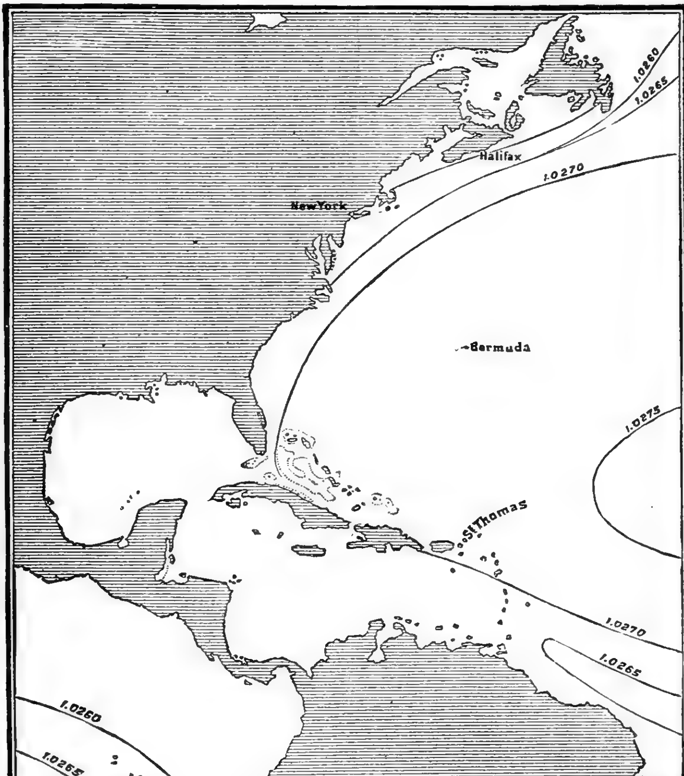


Fig. 194.—Specific Gravity of Sea-Water. Western N. Atlantic. (Buchanan.)

Bahamas, it varies between 1.0270 and 1.0275. In the Caribbean and Gulf of Mexico, as well as waters parallel to the Atlantic coast as far as Cape Hatteras, and after that along the course of the hundred-fathom line, it is between 1.0265 and 1.0270. For the waters within a line drawn from Newfoundland to Cape Cod, the specific gravity is below 1.0260.

The saltest water was found by the "Challenger" in the middle

North Atlantic, in the heart of the region of the tradewinds, and in the South Atlantic in the corresponding regions to the east of the coast of Brazil. To determine from its density the salinity of the water, the water specimens were reduced to its value at a standard temperature, from the tables prepared by Professor Hubbard of Washington, and slightly corrected by the physicists of the "Challenger."

The salinity is affected by the fixing of the salts held in solution, which, like lime and silica, are precipitated, as it were, by organic substances.

In the regions of great rainfall near the equator, the surface water is frequently quite fresh; and in the temperate zone there is nearly an equilibrium between the rain and evaporation. To these subdivisions of concentration and precipitation Thomson assigned an important part in the formation of oceanic currents, for these result from the constant interchange of vapor and water between the air and the sea.

It is interesting to compare the density of the Caribbean and that of the Gulf of Mexico (below 1.0270), both enclosed seas, but supplied with water from a region of low specific gravity (between 1.0260 and 1.0270), with the high density of seas, like the Red Sea and the Mediterranean (above 1.0280), where evaporation goes on with immense activity, although they are both in communication with oceanic basins. In connection with this we might also compare the density of Hudson's Bay with that of the Baltic, and that of the Great Salt Lake with that of the Dead Sea and the Caspian, representing climatic conditions totally unlike.

As has been well said by Moseley, we live in the depths of the atmosphere, just as deep-sea creatures live in those of the sea; but our range, measured by the difference of temperature, is far wider than that to which deep-sea animals, even when subjected to the greatest extremes, are exposed. Terrestrial animals can withstand differences of heat and cold far better than marine animals. The difference of temperature between an arctic winter and a tropical summer, for instance, is from three to four times as large as the widest range of temperature to which any marine animal can be subjected. The lowest tem-

perature to which man is known to have been exposed is probably 78° F. below zero, while in the Colorado River desert a maximum temperature of 120° is not uncommon. The highest temperature of the surface of the sea is about 89°, and the lowest only a couple of degrees below freezing.[1]

It is well known that many species of marine invertebrates have a range in depth corresponding to the whole scale of this difference of temperature, say 60°, while in the case of land animals the extremes differ by nearly 200°. But the facts are exactly opposite where pressure is concerned. At moderate heights, when compared to the whole depth of the atmosphere, the conditions of pressure are sufficiently changed to affect most painfully all terrestrial animals; indeed, these animals are practically limited in their range to a small proportion of the total depth of the atmosphere. With marine animals the conditions are reversed. A difference in bathymetrical range, in which a marine animal may pass from a pressure of a few pounds to the square inch to as many hundred is not uncommon; while a difference of twenty pounds to the square inch will represent the maximum to which terrestrial animals can with safety be subjected.

Enormous as is the range of pressure which marine animals can endure, it is not to this, but to the slight differences in the temperature of the succeeding belts of the sea, that we must look for an explanation of the principal causes of bathymetrical distribution. The heat of the sun, judging from the temperature sections, does not extend farther than to a depth of one hundred and fifty fathoms. This is the range within which at different latitudes are limited the widest variations of temperature (to about 50° F.), and the range within which the oceanic faunæ, as formerly understood, are restricted. Below this belt — of different depth, according to the latitude — we find a second belt of from three to four hundred fathoms, within which the temperature falls very rapidly (to about 38°), until it reaches the depth at which the remaining mass of water may practically be said to have a uniform temperature, varying only

[1] The highest surface temperatures have been observed in the Red Sea, the Gulf of Mexico, and along the Guatemala coast.

between that of 38° and one near the freezing point. Of course, the depth at which the belt reaches the surface will change according to the latitude of the intermediate zones of cold and of the coldest water. The belt of variable heat is deepest in the tropics, while the belt of maximum cold reaches the surface in high latitudes.

In these belts of temperature, we can most satisfactorily trace the so-called faunal districts into which the shores of our continents have been subdivided. The recognized geographical provinces, circumscribed, as first pointed out by Dana, by the lowest degree of cold to which they are subject, comprise, as a general rule, animals living along the shores stretching north and south within certain limits. The bathymetrical range of these littoral species is small, and with few exceptions they do not live within the limits of either the continental or the abyssal areas, where flourish the faunæ of the other two belts. The temperature of the continental belt is sufficiently low to crop out in high latitudes, and hence the large number of so-called arctic species which have been found to be quite common in moderate depths upon this so-called continental area; while the strictly deep-sea or abyssal forms rarely occur within the range of the continental, and still more rarely within that of the littoral belt.

In making a comparison between the atmospheric and watery envelopes of the earth, it is interesting to compare the high velocity of the atmospheric currents and their cataclysmic disturbances with the slow movements of the strongest oceanic currents, — the direction of the atmospheric currents being more nearly what those of the ocean would be were it not for the disturbing effects of continental masses; to the action of these currents we undoubtedly owe the general drift of the surface flow of the oceanic basins. This, in connection with the thermal differences and variations in specific gravity, would produce surface and under currents, modified in their turn by the rotation of the earth.

The general conditions of temperature below five hundred fathoms are very simple. From there an immense body of cold water with a temperature of less than 40° (as low as 33.36°, or near the freezing point), stretches to the bottom of the

oceanic basins. And this is the temperature of all seas which are not, like inland seas, subjected to special conditions ; as, for instance, the Mediterranean, the Red Sea, the Sulu Sea, the Caribbean, and the Gulf of Mexico. These all depend for their lowest bottom temperature on the height of the ridges separating them from the general circulation.

The differences of temperature observed over extensive areas in the Atlantic are easily explained by the presence of ridges rising to heights which isolate the western basin of the Atlantic from the eastern, and that protect these basins again from the indraught of cold water from the depths of the South Atlantic. We may thus find enclosed seas or circumscribed oceanic areas with higher bottom temperature than adjoining seas, due entirely to their exclusion from oceanic circulation by elevations of a portion of the bottom.

The great cold of the bottom water of the ocean, even in the tropics, is best brought home to those who have examined the contents of a haul of the trawl under the tropics. The bottom ooze is intensely cold, and it is a strange sensation, while one's back is broiling beneath a tropical sun, to have one's hands nearly frozen from the stiff, cold mud or ooze one is compelled to handle while assorting the contents of the trawl.[1]

The increase of temperature as one passes into the interior of the earth does not affect the temperature of the bottom of the ocean, for there the constant renewal of cold water supplied from the poles keeps the temperature uniform even in the equatorial regions. Were the body of water affected in a similar manner as the solid crust of the earth, we should find about 350° F. at a depth of three thousand fathoms. But if the increased heat of the interior of the earth's crust is due to pressure, and not to solar agency through the absorption of heat, we can see some reason for a lower ocean temperature at corresponding depths, even were there no oceanic circulation.

[1] We followed the advice given by Commander Belknap to dredgers and sounders, to ice their wine in the common refrigerator ; but the fate of a small bottle of champagne, sent down to a depth of twenty-four hundred fathoms, was only encouraging to the friends of total abstinence. It came back to us cold, it is true, but filled with muddy salt water, which had been forced through the foil and cork, and had replaced the more palatable contents of the bottle.

The oceans, through convection, are the great moderators of climate, carrying north the heat of the tropics, while the cold water of the arctics gradually finds its way to the tropics to be heated, and start on its northward voyage again at a high temperature. By this action in past geological periods, we may seek to explain the remarkable climatic conditions which have characterized the cretaceous and the tertiary. Atmospheric temperature rapidly decreases as we rise to high altitudes, into regions where the pressure is reduced, or pass from the tropics to the north, where the conditions of pressure are nearly the same. In the ocean, where the action of the sun is limited to a comparatively shallow belt, the water having the greatest density is by no means that having the highest temperature. Oceanic circulation is very slow; and, as in the case of the atmosphere, there are no enormous changes of temperature affecting the whole fluid envelope.

The pressure to which animals living in deep water are subject is enormous. At a thousand fathoms, it can be roughly stated to be a ton to the square inch, — more than a hundred and twenty times the pressure borne by terrestrial animals at the level of the sea. Deep-sea animals are probably no more conscious of the pressure acting upon them than animals living on dry land; and they undoubtedly bear, within certain limits, much greater extremes of pressure. A difference of pressure due to a height of twenty thousand feet is perhaps the utmost terrestrial animals can stand; while some invertebrates with a wide bathymetrical range may be subject either to the ordinary pressure of shallow waters, or, if living near the three-thousand-fathom line, to nearly four hundred atmospheres.

Marine animals readily adapt themselves to these immense pressures. Their tissues are permeated by fluids, and perfect equilibrium is established between their circulation and the medium in which they live. Hence pressure has scarcely any effect upon them, as is proved by the wide bathymetrical range of a number of invertebrates, and even of fishes belonging to families in which the bony skeleton remains more or less cartilaginous. Fishes and mollusks are apparently the only animals which show very markedly the effect of a diminished pressure.

In fishes brought up from deep water, the swimming-bladder often protrudes from the mouth, the eyes are forced out of their sockets, the scales have fallen off, and they present a most disreputable appearance.

Regnard's experiments on the effects of pressure — experiments producing a pressure fully as great as that to which they are subject in deep water — indicate that algæ, infusoria, mollusks, worms, and even fishes, are thrown by pressure into a torpid condition, from which they recover after a time when placed again in normal conditions. If the pressure is very powerful and long-continued, it proves fatal to fishes.

But few experiments have been made to ascertain the depth to which light penetrates. They seem to show that a depth of about two hundred fathoms is the lower limit. Forel proved that in the Lake of Geneva photographic plates remained sensitive to between thirty and fifty fathoms, a depth at least four times that at which the presence of a white disk sunk below the surface could be detected, according to the experiments tried by Pourtalès.

These experiments, however, do not determine the limits at which very faint rays of various colors may reach considerable depths. Secchi found that red, yellow, and green successively disappeared, while blue, indigo, and violet remained quite bright at a depth of about forty fathoms. This may explain why, among so many of the deep-sea echinoderms and other animals, violet pigments seem to be the most prominent; yet it has been assumed that the presence of red and carmine among abyssal crustacea and the like proves that the red rays have the greatest penetration. We may imagine a reddish yellow twilight at a depth of about fifty fathoms, passing into a darker region near the hundred-fathom line; and finally, at two hundred fathoms, a district where the light is possibly that of a brilliant starlight night.[1]

M. Edouard Sarasin and Professor Fol recently made an interesting report of the experiments conducted by the committee of the Physical Society of Geneva to ascertain the transparency of

[1] Professor Verrill has made the rather startling suggestion, that in deep water there may be a soft green light, not unlike a pale moonlight.

the water of the lake, and the depth to which light penetrates. Three candles in a lantern — the flame being fed by a continuous current of air — were visible at a depth of thirty metres, in pure water. An electric light was distinctly seen at a depth of thirty-three metres. A few centimetres more, and the clear image disappeared. It was replaced by a diffuse light, faintly perceptible at sixty-seven metres.

Messrs. Sarasin and Soret noticed a very characteristic absorption ray (in the red near B) in the spectrum light which had traversed a certain layer of water. They further observed that the distance of clear vision varied very little with the increase of the brilliancy of the luminous body and its absolute dimensions. Photographic experiments in the deep portions of the lake showed the effect of light on the sensitive plates down to two hundred and fifty metres. This depth seems to be, at least for the plates now in use, the extreme limit of action of the sun's light. "Below this point the lake is a vast dark chamber."

In March, 1885, Messrs. Fol and Sarasin concluded, from their experiments at Villefranche, that in fine weather the last rays of light were dissipated at a depth of about four hundred metres below the surface of the sea.

Nowhere can the effect of light, heat, and motion be better realized than on any beach in the tropics, or upon a coral reef. There, exposed to the full glare of a tropical sun, a profusion of animal life flourishes, unknown in more temperate latitudes. We meet its parallel again in the arctic regions, where an immense number of specimens developed during the long arctic days replace the diversity of forms of tropical realms. The varying conditions of rocky coasts, of long sandy stretches, of mud flats, of gravelly beaches, — whether exposed to or sheltered from the action of the sea, — whether situated in deep or shallow water, in the tropics, the temperate, or the polar regions, — give us an almost endless variety of physical conditions under which our marine fauna and flora flourish, in striking contrast with the conditions in the abyssal and intermediate districts of the oceanic basins.

Pelagic animals, living as they probably do within a belt 150

fathoms in depth, must habitually move, when they come to the surface, from regions of darkness through tracts gradually becoming lighter, until they strike the top of the water, which they find flooded with white light. The range of the nature of sunlight which they pass through is far greater than any we can experience in going from the level of the sea to the highest mountain summits. But the phenomenon of the green light of the sea, gradually replaced near the surface by white light, must be similar to the one so well described by Langley, when he ascended Mount Whitney to a height so much nearer the upper limits of the atmosphere that the color of the sun appeared blue, owing to the disproportionate amount of blue and violet tints, which have been mainly resorbed selectively by the upper layers of the atmosphere, allowing only the white rays to reach us.

In discussing the question of the penetration of light to great depths, we should not forget, on the one hand, that blind crustacea and other marine invertebrates without eyes, or with rudimentary organs of vision, have been dredged from a depth of less than 200 fathoms, and, on the other, that the fauna, as a whole, is not blind as in caves, but that by far the majority of the animals living at a depth of about 2,000 fathoms have eyes either like their allies in shallower water, or else rudimentary, or sometimes very large, as in the huge eyes developed out of all proportion in some of the abyssal crustacea and fishes, and undoubtedly adapted to make the most of the little light existing in deep water. These, as well as the appendages of such deep-sea fishes as the Lophioids, intended to attract prey, seem to tell us something of the exceedingly faint light, or of the actinic rays which alone may reach them through the apparently transparent water.[1]

The eyes of the deep-water fishes, crustacea, cephalopods, gasteropods, annelids, echinoderms, and cœlenterates, are in general identical in structure with those of the same classes living upon the coasts in shallow water. We know little regard-

[1] At a distance from the shore, out of reach of all the sediment brought down by rivers, or washed from the continental shelf by the action of the waves and currents, sea-water is remarkably clear, and free from impurities.

ing the vision of marine animals, and we should be careful in drawing conclusions with reference to physical conditions derived from the functions of organs of sense, which may serve other purposes than those of vision alone. The sense organs of cœlenterates and of annelids, varying between mere pigment spots and more complicated organs, may be of use, not only to detect differences in the intensity of light, but also in receiving other impressions, — of sound, motion, or heat.

The deep-water gasteropods, with rudimentary eyes, or totally blind, live as do their littoral congeners, buried in mud. The blind fishes belong to families with burrowing habits, and living in the soft deep-sea mud. Their organs of vision may gradually have become atrophied, and been replaced by highly specialized tactile organs. The same thing occurs with crustacea. *Astacus zaleucus* is blind, its claws are long and delicate, and with similar tactile organs must be of assistance to them in enabling them to feel their way about. Dr. Carpenter and Professor Thomson came to the conclusion that phosphorescent animals play an important part in lighting up the abyssal regions of the sea. The contents of the trawl are frequently brilliantly phosphorescent, and among the denizens of the deeper regions are a number of highly luminous anthozoa, ophiurans, hydroids, crustacea, and even fishes. Swimming or creeping between the forests of gorgonians,[1] which become luminous by disturbances due to currents or other movements, the deep-sea crustacea, fishes, cephalopods, echinoderms, and others, must be able to see a considerable distance during the emission of the phosphorescent light, and thus receive assistance in searching for their food. The light developed from such a source, and in such a manner, cannot be very intense, and yet such areas may be, as has been stated by Moseley, favorite spots where deep-sea animals congregate. It has been suggested by Professor Verrill that this phosphorescence is protective, and may prevent fishes and other animals from browsing on the luminous actinozoa, lest they

[1] Such forests we find commonly on the shallower slopes of the continental areas, as on the Florida plateau for instance, where the masses of animals accumulated within quite limited areas are really prodigious.

should be stung by large lasso-cells. According to fishermen, fishes avoid nets when filled with phosphorescent animals; yet on coral reefs fishes are constantly seen browsing upon the corals and shoals of gorgonians. The commensalism of many acalephs and quite delicate fishes living surrounded by the tentacles of medusæ, and especially by the intensely burning tentacles of Physaliæ, would seem to prove that they are not in dread of lasso-cells.

During the voyage of the "Challenger," Professor Moseley[1] made a series of spectroscopic observations on the coloring-matters of various deep-sea invertebrates. Special attention was paid to spectra presenting isolated bands, because they are readily identified. He says:—

"Peculiar coloring-matters giving absorption spectra have now been found to exist in members of all the seven groups of the animal kingdom. Amongst Protozoa such coloring-matters occur in Infusoria and Sponges; amongst Cœlenterata they occur both in Anthozoa and Hydromedusæ, in Echinodermata, in both Crinoidea, Echinoidea, and Holothuroidea, but not in the Asteroidea. In Vermes, in Annelids and Gephyreans. In Arthropoda, in Crustacea and in Insecta. In Mollusks, in Gasteropods only. In Vertebrata, in four fish, three species of Odax and one Labrichthys, and twelve birds of two closely allied genera. The Echinodermata and Cœlenterata appear to be the groups which are most prolific of such coloring-matters. Pentacrinin and Antedonin seem to be widely diffused in immense quantities through the tissues of the crinoids in which they occur; and Echinoderms generally seem to be characterized by the presence of evenly diffused, abundant, and readily soluble pigments.

"It seems improbable that the eyes of other animals are more perfect as spectroscopes than our own, and hence we are at a loss for an explanation, on grounds of direct benefit to the species, of the existence of the peculiar complex pigment in it. That the majority of species of Antedon should have vivid coloring-matters of a simple character, and that few or one only should be dyed by a very complex one, is a remarkable fact, and it seems only possible to say in regard to such facts, that the formation of the particular pigment in the animal is accidental, *i. e.*, no more to be explained than such facts as that sulphate of copper is blue."

Professor Moseley also observed that the phosphorescent light

[1] Quart. Journ. Mic. Science, XVII., 1877, p. 1.

emitted by alcyonarians consisted of red, yellow, and green rays only.

"Hence, were the light in the deep sea derived from this source, in the absence of blue and violet, only red, yellow, and green colors could be effective. . . . A brilliant green coloring-matter was found in some deep-sea Annelids. No doubt in many cases the coloring of the deep-sea animals, as in the case of the purple Holothurians, is useless, and only a case of persistence. The madder coloring of some of the soft parts of the Corals may be in like case, but possibly useful for attraction of prey, being visible by the phosphorescent light. . . .

"The same coloring-matters exist in deep-sea animals which are found in shallow-water forms. In the case of deep-sea possessors of these pigments, they perhaps never exercise their peculiar complex action on light during the whole life of the animal, but remain in darkness, never showing their color."

Many of the deep-sea fishes collected by the "Blake" are of a grayish color, or a dull black, or have as it were lost their color, and been bleached to a dirty white; they resemble in this respect semi-transparent fish embryos, in which black is still the most characteristic pigment. No blue animals have been noticed among the deep-sea types; blue is, in spite of its apparent protective color, rarely seen in marine animals, except in a few pelagic forms.[1] Deep-sea burrowing animals have fully as marked a diversity of coloring as their shallower water congeners. There is apparently in the abysses of the sea the same adaptation to the surroundings as upon the littoral zone. We meet with highly colored ophiurans within masses of sponges, themselves brilliantly colored, at a depth of more than 150 fathoms.

Again, other ophiurans, coming from the globigerina ooze, could hardly be seen when stretched out on its surface. As in shallower waters, they must live buried in this material, from which they can scarcely be distinguished. It seems difficult to believe that protective characters which are of use in waters of moderate depths should have been retained in deep-sea types,

[1] We must except a small incrusting sponge of a blue color, not uncommon in the dredgings near the hundred-fathom line in the Gulf of Mexico, as well as blue eggs of a crustacean living buried in large masses of sponge.

which have flourished for long periods of time in regions far beyond those where protective coloration would be of service. We have a strong argument in favor of the gradual and comparatively recent migration of littoral forms into deep water in the fact that there are still so many vividly colored bathyssal animals belonging to all the classes of the animal kingdom, and possessing nearly all the hues found in types living in littoral waters.

While we recognize the predominance of tints of white, pink, red, scarlet, orange, violet, purple, green, yellow, and allied colors in deep-water types, the variety of coloring among them is quite as striking as that of better-known marine animals. The fishes belonging to the lophioids, to the labroids, to the wrasses, and to the scorpænoids, remind us in their coloring of that of their littoral allies. There is as great a diversity in color in the reds, oranges, greens, yellows, and scarlets of the deep-water starfishes and ophiurans as there is in those of our rocky or sandy shores.

Among the abyssal invertebrates living in commensalism, the adaptation to surroundings is fully as marked as in shallow water. I may mention specially the many species of ophiurans, attached to variously colored gorgonians, branching corals, and stems of Pentacrinus, scarcely to be distinguished from the part to which they cling, so completely has their pattern of coloration become identified with it. There is a similar agreement in coloration in annelids when commensals upon starfishes, mollusca, actiniæ, or sponges, and with crustacea, and actiniæ parasitic upon corals, gorgonians, or mollusks. The habits of the deep-sea hermit-crabs are not unlike those of their shallow-water species, and there are deep-water pygnogonids associated with hydroids. Deep-water cephalopods do not differ in their type of coloration from those of the coast shelf.

The echinoids dredged beyond the hundred-fathom line are many of them dark-colored, but generally present, as in the case of the spatangoids, the neutral colors that are characteristic of those living at higher levels on sandy beaches, or do not differ in their tints from those of the littoral zone as in the case of the many species of Echinus proper.

Among the actinians brought up from deeper water, red, orange, or rosy and flesh-colored tints and stripes are as abundant as in the more common species of shallow water. The dominant colors of gorgonians are orange, red, green, violet, yellow, fully as varied an assortment as exists in the anthozoa of a flourishing coral reef.

The number of species of crustacea (schizopods, peneids, caridids) colored a brilliant scarlet is quite large, and it is somewhat remarkable, as has already been noticed by Moseley, that a pigment which is seen occasionally in some of the more minute pelagic crustacea should be so abnormally developed in deep water. In other deep-sea crustacea there is a predominance of shades of yellow, pink, and pale greenish tints.

Large masses of sponges of a brilliant orange-yellow or brownish pink are constantly dredged from depths near the two-hundred-fathom line, associated with species having the colors of the littoral sponges. In the deep-sea comatulæ the coloring is similar to that of the shore species. We have violet, green, reddish yellows, and browns, the prevailing tints. Among the stalked crinoids the tints vary from cream-colored to dark green or grayish violet. The coloring principle, pentacrinin, dissolved in alcohol, produces an intense purple red.

The distribution of marine plants[1] plays an important part

[1] The recent observations of Berthold in regard to the bathymetrical range of algæ indicate clearly that the principal features in their distribution are light and the motion of the water. The species characteristic of localities exposed to violent action of the waves are different from those found in more protected places. There are algæ which require intense light, and others which flourish best in sites sheltered from direct action of the sun.

The green and brown algæ need the greatest amount of light and motion, and flourish in those limits of the shores which are closest to the high-water mark, while on the contrary the red algæ live in deeper water, where the light is more diffuse, and the motion somewhat lessened. The calcareous algæ thrive in quiet waters, though they are not, at least in the tropics on reefs, affected unfavorably by a flood of light. Berthold states that they are still found in great quantities in deep water, — sixty fathoms in the deepest parts of the Gulf of Naples. The intense light and heat of the tropical seas may perhaps be the primary cause of the absence of an extended marine flora. Yet light and heat are most important to the extensive pelagic flora, and in the tropical regions in the track of oceanic currents there are vast fields of surface algæ, often discoloring the sea for miles. The fullest development of our coast algæ undoubtedly takes place in the temperate regions, and the fact that some of the larger fronds of Macrocystis have a length of 150 fathoms, and that some of the cal-

in the food supply of shore animals; vegetable life forms the basis of all life; for while many animals are carnivorous, yet those they feed upon depend in a measure for their sustenance upon plants. It is therefore an interesting problem to ascertain how far vegetable life extends into the depths of the sea. Its disappearance in comparatively shallow regions is a remarkable phenomenon, when we remember that all animal life is ultimately dependent upon vegetable life for its own existence.

The discovery of the carcasses of pelagic animals at the bottom of the ocean, still fresh enough to supply a large amount of food for the animals constituting the deep-sea fauna, solves the problem at once. The pelagic animals derive a large part of their food supply from the swarms of large and small pelagic algæ covering the surface of the sea in all oceans. On dying, both surface animals and plants drop to the bottom, and still retain an amount of nutritive matter sufficient to serve as food for the carnivorous animals living on the bottom. The pelagic fauna thus becomes the medium of transfer to the bottom of a large quantity of vegetable matter living at the surface. This transfer takes place rapidly. Moseley says Salpæ will sink two thousand fathoms in less than three days.

The larger carnivorous animals of course prey upon one another, but foraminifera, sponges, and their allies, cannot feed upon each other, as do the mollusks, annelids, polyps, and the like. They need vegetable substances, or diluted organic matter, such as they find in abundance on the bottom.

A sort of "broth," as it has been called by Carpenter, collects on the bottom of the ocean, from which the lower types may possibly be able to obtain their sustenance directly, and transfer it for their uses, as they do the silex and lime which they get

careous algæ are found at that depth, would prove conclusively that some kind of light penetrates to this depth. Some of the organisms which have been described as single-chambered foraminifera are in reality calcareous algæ, allied to the green spore-bearing algæ, the Dasycladæ of Harvey.

Boring algæ have been dredged in deep water (over 1,000 fathoms).

At a depth of 270 fathoms off Havana, Pourtalès dredged a single specimen of a minute alga, *Centroceras clavulatum* Aghard, which Harvey says is common at low-water mark at Key West. Diatoms were also brought up from the same locality.

in solution in the sea. This broth probably remains serviceable for quite a period of time; the decomposition of the organic material which has found its way to the bottom takes place gradually, and its putrefaction must be very slow.[1] This broth is derived not only from the pelagic fauna and flora, but also, along the littoral and continental zones, from the decomposition of animal and vegetable detritus washed from the shore belts, or swept by the rivers into the sea, or carried into deeper water by slowly moving currents. Though we are only beginning the investigation of the physical conditions of the ocean, we have learned enough to see how necessary to any exposition of the evolution of the present condition of our earth is a knowledge of the physics of the sea.

[1] M. Certes (*Acad. Royale de Belgique*, Bull. VII., No. 6, 1884) has shown the presence of microbes at considerable depths, 250 to 2,500 fathoms, and of a large number of tests he made, only four have given no result. He submitted a bacterium to a pressure of 600 atmospheres, and found that this did not affect it. He seems to think the effect of pressure varies with each species, and that no littoral species can resist an excessive or prolonged pressure.

Regnard (*Comptes Rendus*, Mars 24, 1884, p. 745), who also experimented on the effect of great pressure, found that while under a pressure of six hundred atmospheres yeast mixed with a solution of sugar showed no signs of fermentation. This pressure is equal to a depth of nearly 4,000 fathoms.